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EDITORIAL

The Development of Dry Zone Pastures

RECENT RESEARCH at Maha Illuppallama has compelled a restatement of land use policy in the Dry Zone with increased emphasis on livestock production, and closer integration of crops with animal husbandry. The system of land use evolved at Maha Illuppallama allocates to permanent pasture, the lower segment of the catena that composes a Dry Zone catchment; the "unirrigable lowlands" are ideal for grass but unsuitable for annuals except upland rice. As an extent of nearly 1.8 million acres in the region below the 75-inch rainfall contour falls within this land, tremendous potentialities for pasture development exist.

The lack of a pastoral tradition severely handicaps the promotion of a livestock industry in Ceylon. Not only is the Ceylon farmer totally unfamiliar with techniques of pasture establishment and management, but no indigenous grasses suitable for exploitation as pasture components occur. The agrostologist is compelled to ransack the world's grasslands for satisfactory species. In 1949, the Botanist of the Department of Agriculture imported from Kenya, a consignment of seed of the grass, *Brachiaria brizantha.* For cytological reasons, this species generally sets non-viable seed, but the Botanist succeeded in nursing a single plant to maturity. The solitary survivor was increased so rapidly in the last decade, that today this clone of *Brachiaria brizantha* covers many thousand acres of State and private land, and will, for many years to come, form the basis of this country's pastures. The performance of this grass in its country of origin has been unimpressive. In Ceylon, on the other hand, it is supreme among pasture grasses. According to the findings at Maha Illuppallama, this species has a peculiarly high silica requirement: hence possibly its exceptional performance on the silica-rich soils of the Dry Zone.

Brachiaria brizantha has been the subject of intensive investigation at Maha Illuppallama, and Departmental agrostologists are intimate with its behaviour and demands. The protein content of the sward fluctuates with the growth rate, which in turn is a function of rainfall. Wet weather does not merely promote herbage production but raises the protein percentage. The ash content varies *pari passu*

with the protein value. The application of nitrogen and phosphate raises herbage yields, and improves herbage qualtiy. In a management trial at Maha Illuppallama extending over a period of nearly nine months, at a stocking rate of .22 heifers per acre, mean liveweight gains of 1.1. lb. and 1.2 per animal per day for rotational and continuous grazing have been recorded. Stocking rates in the Dry Zone, however, need careful adjustment to the marked seasonal fluctuations in the growth rate of grass, and this is an aspect of management in which precise information is particularly desired.

The problem of a suitable legume component has been only partially solved. Brazilian lucerne (*Stylosanthes gracilis*) has not delivered on its pristine promise. Heavy borer damage and the accumulation of large quantities of " inert " are its chief defects. In temperate latitudes, the associated legume contributes the complete nitrogen needs of a pasture. The achievement of this objective in the tropics presents problems as high temperatures depress nitrogen fixation by rhizobia.

In the Dry Zone, apart from the potentialities for pasture establishment, considerable extents of natural pasture exist. Particularly noteworthy are the rich pasture lands which cover nearly 20,000 acres on the banks of the Mahaweli Ganga, and which the Tamankaduwa Project seeks to exploit. The project, which is phased over six years, envisages the establishment of a Sindhi herd of 5,000 milking cows and ancillary follower and fattening units.

The conditions that obtain in Ceylon's Dry Zone make beef production more profitable than dairying. Dairy cows are more fastidious in their dietary and temperature demands than beef cattle. Nevertheless, in view of the general antipathy to the idea of rearing animals for slaughter, Dry Zone pastures must be devoted to dairying.

A PEDOLOGIC STUDY OF DRY ZONE SOILS*

By

C. R. Panabokke

(Head, Division of Land Use, Dept. of Agriculture, Ceylon)

CEYLON'S WET ZONE soils have successfully accommodated a wide range of tropical plantation crops which have significantly contributed to the economic development of the country. On the other hand, the climate and soil characteristics of the Dry Zone are such, that besides rice culture under irrigated conditions, no productive system of agriculture has yet succeeded in displacing the subsistence form of 'chena' or shifting cultivation. Even after the complete exploitation of the Dry Zone's irrigable resources there yet remains the urgent need to evolve a productive agricultural system for the unirrigable lands which aggregate nearly 2.6 million acres. Problems which the agricultural scientist encounters in evolving such a system have been clearly posed by Abeyratne (1) in a recent publication.

This study which includes a mineralogical study of the clay fraction was undertaken as one of the fundamental projects in 1953 in order to throw some light on the soil characteristics of this region. The area studied was that land opened for the Dry Zone Research Station which covers an extent of 1,200 acres and comprises a typical land unit of Ceylon's Dry Zone. It is situated at an altitude of 380 feet in Lat. 8° 05′ N. and Long. 80° 28′ E.

Climate

The average annual precipitation for the past 53 years has been 57.7 inches with a high of 98.39 inches in 1957 and a low of 31.2 inches in 1956. As seen in Figure 1 there is no definite cycle of wet and dry years.

An important characteristic of the Dry Zone rainfall is the division of the annual rainfall into two well marked seasons. The mean monthly rainfall distribution (Figure 2) shows a bimodal rainfall pattern with two dry seasons : one in February which is short, and the other from June to September which is long and pronounced.

* Contribution No. 5 from the Division of Dry Zone Research.

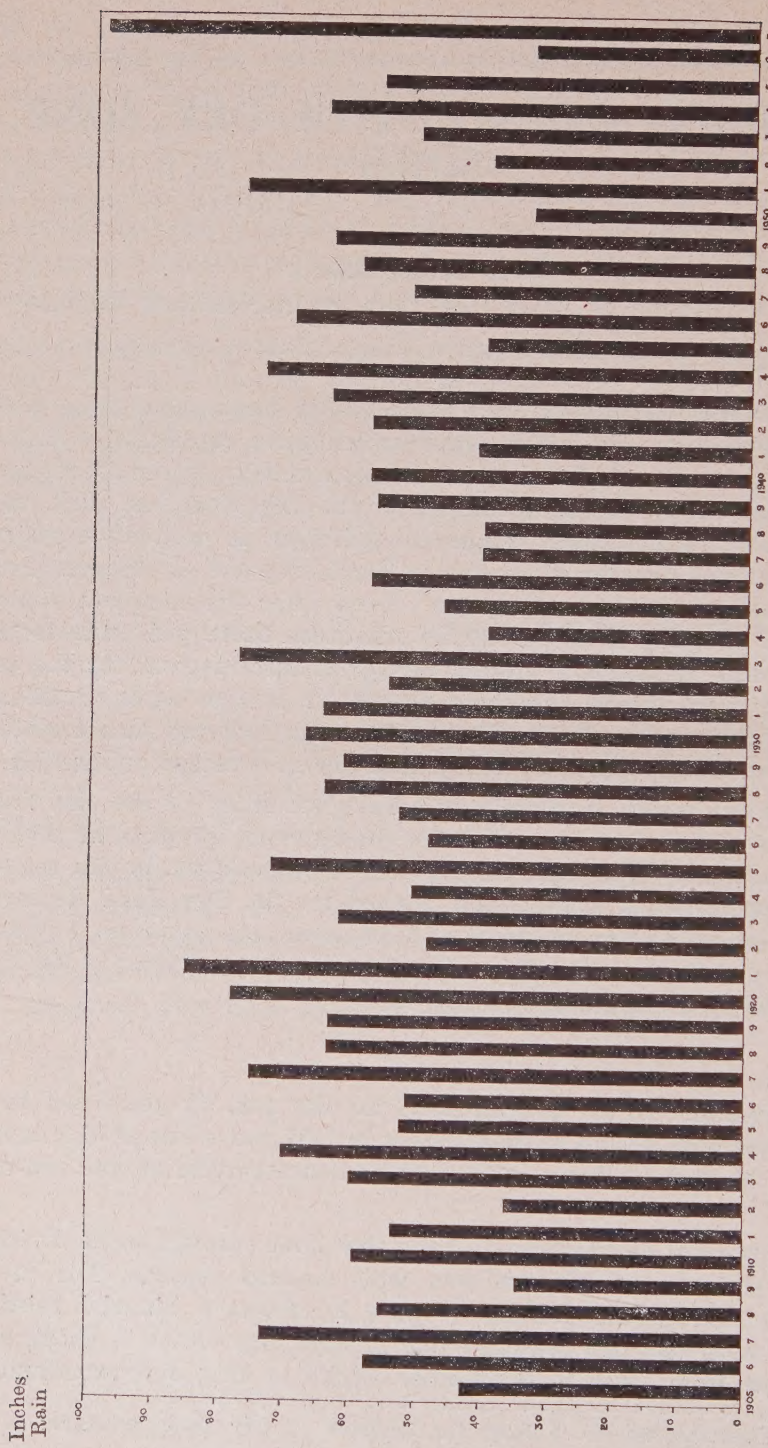


Fig. 1. The yearly total of rainfall over 53 successive years. Each column represents the total for one year.

The main growing season *Maha* commences in September-October with convectional rains which fall in heavy thunderstorms in the afternoon and evenings. Storms of the following intensities have been recorded since 1951.

Two inches in 35 minutes.
Three and a half inches in 70 minutes.
Three inches in 100 minutes.
Four inches in 100 minutes.

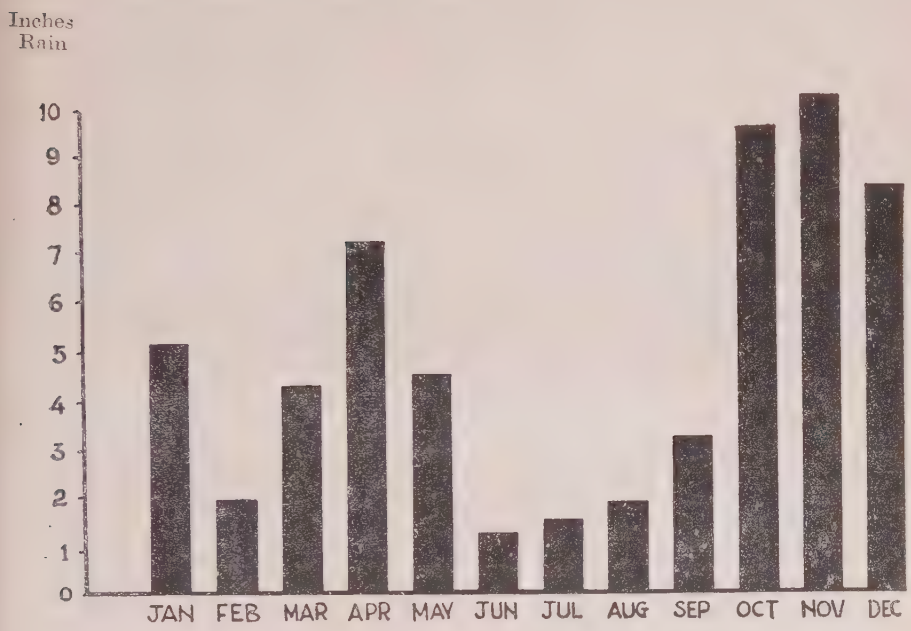


Fig. 2. Monthly distribution of rain; average over 52 years.

A high percentage of this rainfall is lost as surface run-off. Drought periods are liable to occur during this wet season which could last from two to three weeks. The "North-East Monsoon" rains which arrive in mid November and continue up to mid or late January are characterised by an even distribution. The short dry spell from February to mid March coincides with the harvesting stage of the *Maha* crops. A second convectional cycle builds up in March-April which marks the beginning of the *Yala* cropping season which is of short duration. The Dry Zone falls within the rain shadow of the South-West Monsoon and therefore experiences dry desiccating conditions from June to September. Table I gives the maximum and minimum temperatures and relative humidity (average for 12 years), and the sunshine (hours/day), wind velocity, and evaporation figures for 1957.

Soil temperature values for 1957 are shown in Figure 3.

Geology and Geomorphology

A greater part of the Dry Zone lies within the extensive peneplain which Adams (2) recognized as the first peneplain of Ceylon. It is built up of Pre-Cambrian metamorphic rocks of several varieties.

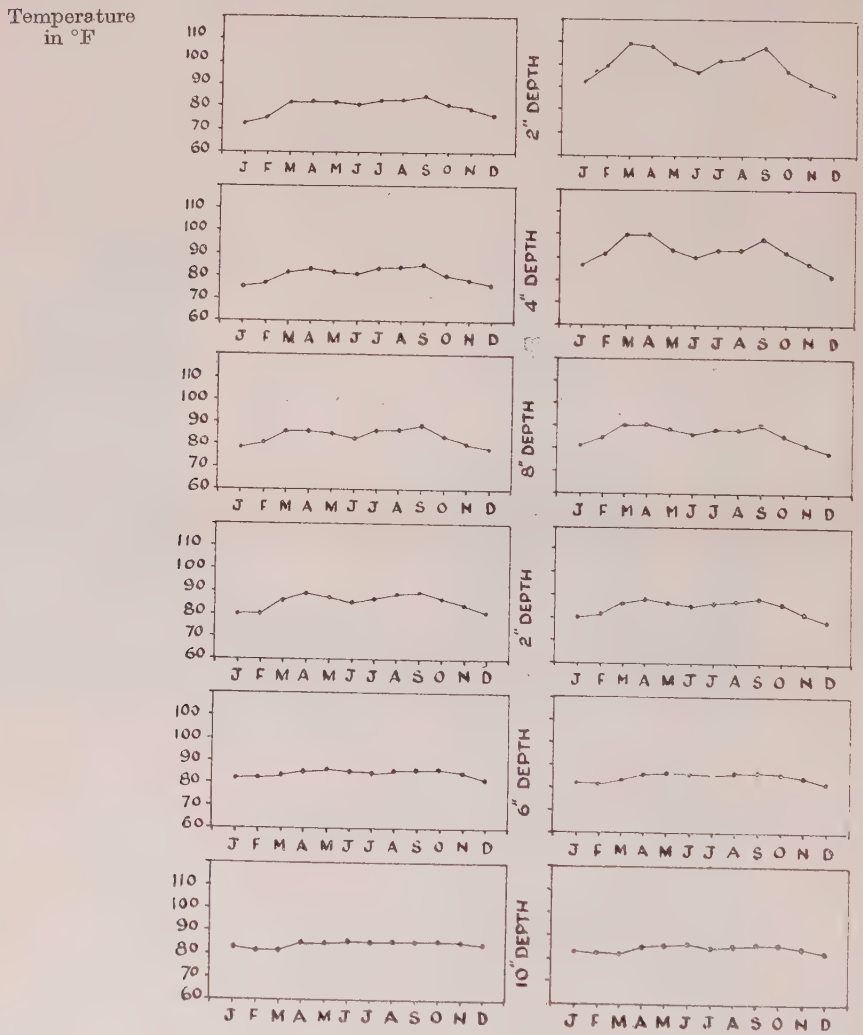


Fig. 3. Soil temperature at different depths (1957).

The area occupied by the Research Station is made up of a complex of rocks which include charnockites, granite gneisses, biotite gneisses and migmatites. Nearly nine-tenths of the Research Station is made

up of coarse-grained charnockitic rocks. The charnockite could be described as a coarse-grained, greasy grey, gneissic rock with lenticles and patches of darker fine-grained basic charnockite. A specific feature of these charnockites is the absence of garnet. Both basic and acid charnockites occur with sharp contacts between the two types, and in some parts the acid charnockite grades into a very acid type with ramifying quartz veins. The granite gneisses are very light coloured, hard rocks containing pinkish feldspar. A narrow consistent belt of migmatite crosses the Research Station in NNW-SSE direction. This migmatite belt appears to have formed by granitization of pre-existing charnockite rocks.

Plate 1. General view of first peneplain showing erosion remnants in distance.

The ancient peneplained surface of Archaean metamorphic rocks grades from sea-level at the coast, to 600 feet above sea-level at the foot of the adjacent second peneplain. This first peneplain is a flat to gently undulating rock-floored plain, with scattered monadnocks or erosion remnants of the more resistant rock breaking the relief (see Plate 1). A few of these erosion remnants rise in places to over 1,000 feet and may be outliers of the upland.

Differential erosion of the peneplain surface has left isolated remnants of the underlying rock outcropping in places (see Plate 2). The land around the base of the larger outcrops is bouldery to rocky due to the accumulation of exfoliated fragments from the outcrops above. In some instances erosion has removed the mantle of weathered

Plate 2. Isolated remnants of outcropping rock.

material from the tops of the ridges leaving small dome like areas of exposed bed rock. Soil erosion has it times taken place in the lower slopes and valleys thereby exposing the underlying rock in the form of isolated outcrops which generally assume a dome shape or sub-angular or jagged shape.

The valleys between the ridges are shallow and moderately wide and they have level to concave floors : the deeper valleys have incised stream channels. The general aspect is therefore of a gently undulating land surface made up of relatively shallow but well defined minor

Plate 3. Aerial view of the Research Station and its immediate environs.

valleys. The terms watershed area or catchment basin are used synonymously to denote a fundamental land unit. In each of these land units the distance from the ridge to the floor of the adjacent valley is never very great: slopes average from 1 per cent. to 5 per cent. Plate (3) shows an aerial view of the Research Station and its immediate environs.

Vegetation

The natural vegetation near the Research Station (see Plate 4) is "a mixed evergreen forest which appears to be seral and secondary in character. The trees are microphylls and mesophylls of both evergreen and deciduous species. The shrub layer up to 10 feet is generally light while the field layer is grassy. There is usually very little leaf litter. Climbers which include large lianas are frequent and add considerably to the cover which is already formed by the dominant overwood."

Plate 4. Natural vegetation near the research station.

Hydrology

A soil mantle of variable thickness with good internal drainage overlies the impermeable crystalline rock. Borings carried out at the Research Station reveal that the average depth of the sub-soil and decomposing rock is around 18 feet. In loci of more intense weathering such as between two parallel ridges it may extend to a maximum of 42 feet. The Research Station is made up of six catchment basins varying in size from 30 acres to 120 acres. The largest of these has a maximum distance of three quarters of a mile and a fall of 40 feet from the crest to the valley floor. Within each of these drainage basins, perforated pipes 1½ inches in diameter, were sunk at intervals along the traverse from the ridge to the valley floor. The ground water level in each pipe was measured bi-weekly using an electric sounding device.

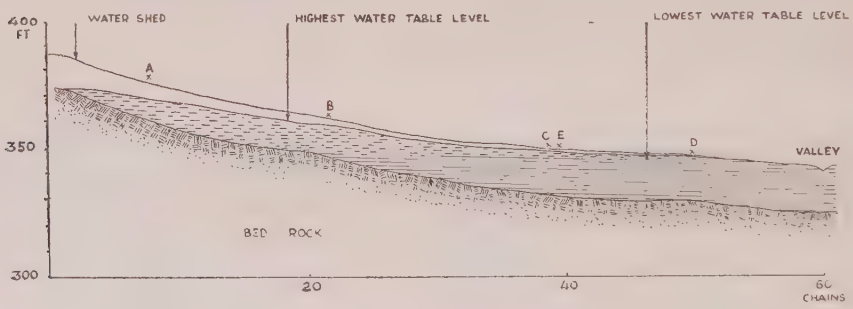


Fig. 4. Water table behaviour (1951–1957)

From the results obtained it is found that the pattern of groundwater behavior is essentially similar in all the catchment basins. The generalised pattern illustrated in Fig. 4 is of one such typical catchment basin. The highest and lowest positions of the water table respectively, which have been recorded since 1951, are shown in this figure. The detailed observations permit of the following conclusions :—

(*a*) On the ridge and the upper slopes there is no water table evident within the depths the borings were made. While this is so during a normal rainfall season, in a season of unusually excessive rainfall the water table rises to within 3 feet of the surface. This land class is therefore well drained during the wet season.

(*b*) In the middle and lower slopes the ground water rises to the surface for a short period, but it disappears during the dry season. This land class is therefore relatively poorly drained during the wet season.

(c) The bottom lands are poorly drained during the greater part of the year because the water table rises to the surface for long periods, and falls to within 3 to 8 feet of the surface during the dry season.

A unique feature of the soils is their soil-water energy relationships. The soils have a narrow range of available moisture despite the average clay content. At wilting point (pF=4.2) the content is 8 per cent ; at field capacity it is 17 per cent ; at maximum saturation the water content is 25 per cent. The available range of moisture is thus only 9 per cent. It is further observed that when drying out the soil loses nearly 85 per cent. of the available moisture at pF=3, or a tension of one atmosphere. As a result, the soils dry out very easily and they also tend to get saturated very quickly after rainfall.

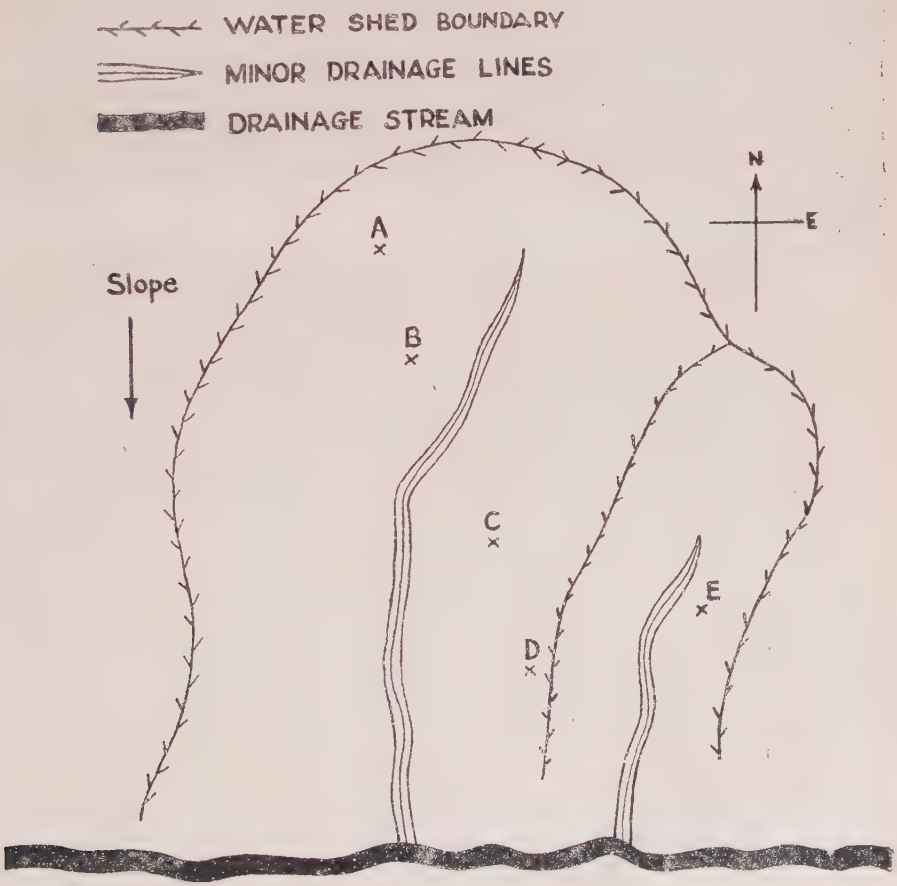


Fig. 5. Locations of profiles.

During the wet season, in spite of the good internal drainage of the profiles, the impervious nature of the underlying rock prevents vertical drainage and the ground-water level therefore builds up. The rise in ground-water level after the onset of the rains is very rapid, and it drops during th dry season at an average rate of about 2 feet per month.

Description of Soils

A catenary sequence of soils ranging from Tropical Red Earths to their hydromorphic variants is recognizable in a traverse from the crest of the ridge to the floor of the adjacent valley. The catena is not necessarily a series of strips of soil running along the slopes parallel to the contours. The normal sequence is interrupted in places by small tributary drainage lines and minor drainage basins. One of the six major catchment basins of the Research Station that had a minimum of such interruptions was selected and four profiles were located down the traverse. A fifth profile was located in one of the minor basins that lie within the main catchment basin. These five locations are shown in Figure 5 as A, B, C, D and E, respectively. Profile E is on the same elevation as profile C. The low lying irrigable areas have been excluded from this study since they have been regularly cultivated from medieval times. The profiles are shown diagrammatically in Figure 6.

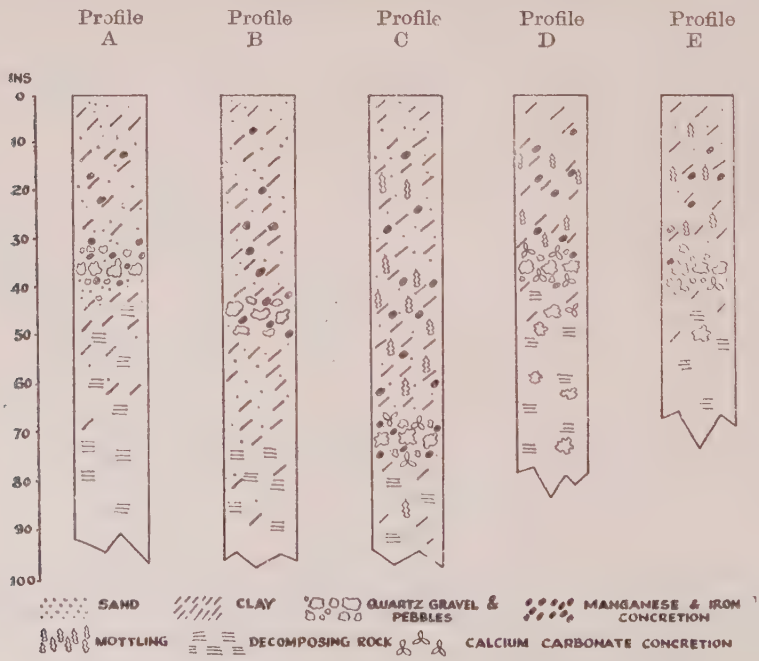


Fig. 6. Profiles shown diagramatically. (Charter's method)

PROFILE 'A'

Drainage good to excessive in both dry and wet seasons

0-9″ Reddish brown 2.5 YR 4/4, sandy clay loam with grit. (Coarse sand and grit mostly quartz). Coarse blocky structure with a vesicular appearance;

—gradual change to ....

9-26″ Reddish brown, 5 YR 4/4, loam with grit, heavier texture and less friable than above; slightly better developed coarse blocky structure; slight vertical cracking; small hard manganese concretions 1-2 mm. in size;

—fairly well defined change to ....

26-43″ Red, 2.3 YR 4/6, gravelly clay loam with quartz cemented by a reddish clay matrix; structureless. Heavy concentration of angular, sub-angular as well as much rounded quartz pebbles of sizes up to 1½″. The bigger pebbles are found concentrated more or less at the centre of the horizon and a gradation in size, both upwards and downwards, to smaller gravel-size quartz is noticeable. Fragments of feldspar and unweathered gneiss. Many hard manganese concretions,

—gradual change to ....

43-57″ Light yellowish brown, 10 YR 5/5, decomposing rock intermixed with red brown soil. Mixture of quartz and feldspar inbedded in a matrix of soil and decomposed rock;

—diffuse change to ....

57-91″ Decomposing rock. A complex mixture of completely decomposed rock, feldspar gravel and unweathered rock fragments. Deeper down there is less of decomposed material and the unweathered rock appears less fragmented as the solid rock is approached.

PROFILE 'B'

Drainage good in both dry and wet seasons

0-9″ Dark reddish brown, 5 YR 3/4, sandy clay loam with grit. (Coarse sand and grit mostly quartz). Coarse blocky structure with certain amount of earthworm casts and slightly vesicular in appearance. Occasional hard manganese concretions:

—gradual change to ....

9-17″ Reddish brown, 5 YR 4/4, loam with little grit. Heavier texture than above; well developed blocky structure with vertical cracks and few earthworm casts;

—gradual change to ....

17-44″ Reddish brown, 5 YR 4/4, slightly lighter coloured than above, loam with grit. Weak blocky structure; abundant hard manganese concretions; few termite passages;

—clear change to ....

44-62″ Dusky red, 10 R 3/4, gravelly clay loam with a quartz gravel layer. Structureless; angular as well as much rounded quartz pebbles are cemented in a reddish clay matrix; many hard manganese concretions;

—clear change to ....

62-72″ Dark red 2.5 YR 3/8, friable red earth; structureless; some fragments of decomposing feldspar;

—diffuse change to ....

72-90″ 10 YR 6/6. Decomposing rock with soft porous red earth mixed with highly weathered quartz.

PROFILE 'C'

Drainage good in dry season and imperfect in wet season

0-7″ Yellowish brown, 10 YR 5/4, sandy loam with sub-angular grit. Very weakly developed blocky structure and vesicular appearance; few hard manganese concretions;

—gradual change to ....

7-29″ Dark yellowish brown, 10 YR 4/4, sandy loam. Weak blocky to prismatic structure with faint vertical cracks. Mottled appearance caused by the iron staining and manganese concretions. The manganese concretions are soft and diffuse with a rust coloured periphery. This horizon shows slight induration;

—gradual change to ....

29-70″ Very dark grey brown, 10 YR 3/2, sandy clay loam. Massive to blocky structure. The mottling is more pronounced than in the above horizon. The manganese concretions are also softer and bigger. Calcium carbonate concretions occur at 35″ depth. Certain amount of induration observable;

—well defined change to ....

70-75″ Olive brown, 2.5 Y 4/4, gravelly clay loam. Structureless. Heavy concentration of quartz gravel and pebbles as well as unweathered fragments of feldspar. Hard calcium carbonate concretions. Few dark roots showing a petrified appearance are observable;

—diffuse change to ....

75-91″ Pale yellow, 2.5 Y 9/4, with some mottling. A mixture of decomposed rock and unweathered fragments of feldspar with a moderate amount of clay.

PROFILE 'D'

Drainage fair in the dry season ; imperfect during the wet season

0-7″	Grey brown, 10 YR 5/2, sandy loam with fairly rounded grit. Structureless, to very weakly developed blocky structure. This horizon had a slightly bleached appearance ; —gradual change to ....
7-20″	Dark brown 10 YR 4/3, sandy loam with rounded and angular grit. Weak blocky structure more compact than above. Considerable mottling in the form of rusty streaks on a grey background. Soft diffuse manganese concretions and small bright red iron concretions. This horizon appears slightly indurated ; —fairly well defined change to ....
20-34″	Lighter dark brown than above, but heavier in texture. Mottling is darker and more pronounced than above. The manganese concretions are bigger than above. Calcium carbonate concretions occur at the 33″ depth ; —clear change to ....
34-36″	Yellowish brown, 10 YR 5/4, gravelly layer with angular and sub-angular quartz gravel. Structureless. The quartz gravel and feldspar are intimately mixed. Hard nodular calcium carbonate concretions. Dark roots having a petrified appearance ; —diffuse change to ....
36-52″	Very pale brown, 10 YR 7/5, granular decomposing rock with calcium carbonate concretions extending into this horizon.
52-75″	Soft decomposing rock with very little quartz gravel.

PROFILE 'E'

Drainage moderately good in dry season ; imperfect during the wet season

0-4½″	Light grey brown, 10 YR 6/2, sandy loam with grit. Weak crumb to blocky structure ; —gradual change to ....
4½-18″	Light grey brown, 2.5 Y 6/2, slightly bleached appearance ; sandy clay loam with open blocky structure. Slight mottling with manganese concretions of medium hardness ; —gradual change to ....

18-30″	Light grey brown, 10 YR 6/2, loam slightly darker than above, and also more compact. Mottling due to iron staining and manganese concretions ; —clear change to ....
30-39″	Light olive brown, 2.5 Y 5/4, gravelly clay loam. Structureless, quartz gravel and fragments of feldspar ; —clear change to ....
39-69″	Soft decomposing rock with nodular calcium carbonate concretions at 45″. More dark roots than in other profiles.

Analysis of the Soils

The particle-size distribution [1] of the samples was determined on the soil passing through the 4-mm. sieve because of the high proportion of coarse quartz. The fusion analysis was carried out on the soil passing through the 1-mm. sieve. For methods of fusion analysis, Hillebrand & Lundel (7) and Groves (6) were followed. It was not possible to extend the fusion analysis to K_2O and P_2O_5 because of the limited laboratory facilities available in the early years of this study. Potash and Phosphoric acid were determined in hydrochloric acid (constant boiling point) extracts.

The organic matter was determined by the Walkley & Black (14) method, and pH values were obtained using a glass electrode at 1 : 2.5 soil/water ratio. Total exchangeable cations were determined by the Bray & Willhite (4) method. The results of the above analysis are set out in Table II.

Discussion

The soils have developed on material derived from the underlying gneissic rock. The charnockite, the biotite gneiss and the granite gneiss occur in very close association, so that the identity of the different rock types is not manifested in the ultimate mixture of weathered material. A high rate of natural erosion has prevented the formation of deeper soils. The basic rock, however, weathers to a fairly deep soil, where as the acid rock weathers to a shallow and more coarse-textured soil. Since a very high proportion of the Dry Zone forests have been affected by 'chena' cultivation it is not possible to correlate vegetation boundaries with soil boundaries. It is observed that the vegetation boundaries represent cultivation boundaries rather than soil boundaries.

[1] The clay and silt fractions were determined by the 'International pipette' method.

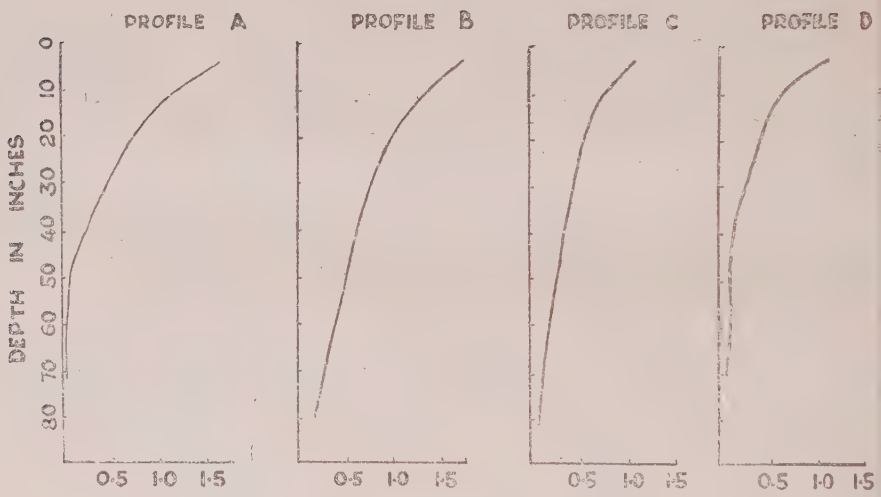
From the description of the profiles and the hydrological features that were discussed earlier, it is clear that the differentiation of the member series of the catena is conditioned by drainage variations.

While in the upper aspects of the slope, soils have formed on residuum, in the lower aspects it is observed that the soil formed on residuum is overlain by a thin deposit of locally transported alluvium which would have originated in the upper slopes and subsequently been brought down by eroding water. Profile descriptions and the particle-size distribution figures in Table II show that the soils on the upper slopes are sandy clay loams while lower down the slope they are sandy loams. Differential movement of soil particles takes place down the slope under the influence of surface run-off: sand particles remain on the slopes while the clay moves down into the valley: thus the valley bottoms are mainly clay loams. Chemical weathering greatly exceeds physical weathering in this climate so that the parent rock is rapidly decomposed into quartz sand, clay, and iron oxides before profile differentiation could express itself. The small proportions of the silt size fraction is a common feature of many tropical soils. The coarse fractions are mainly quartz and heavy minerals: the particle size distribution assumes a bi-modal form. Although the flocculated state of the soil colloid restricts its movement down the profile, there has been a slight movement of clay into the sub-surface horizons.

The Red earths at the top of the catena are formed under conditions where there is nett downward movement of water. Occurrence of limestone concretions in varying depths of the profiles in the lower members of the catena does not warrant their classification as pedocals, because it is not a limiting rainfall which causes this concentration and deposition of the calcium carbonate. Soluble calcium is carried in the seepage water from the higher slopes and this process continues even during the dry season due to a falling water table. Impeded drainage conditions in these lowlying areas coupled with the high evaporation which takes place during the dry season causes the calcium carbonate to be deposited. The impervious underlying strata prevents further leaching of the calcium carbonate during the rainy season. Although it may seem feasible to consider the individual members of the catena as provisional soil series, the foregoing observations emphasise the importance of considering the catena as a unit rather than the conventional practice of considering the soil series themselves as independant units.

The organic-matter contents of the profiles are depicted in Figure 7. It is observed that the better drained profiles A and B have a higher organic-matter content than the imperfectly drained profiles C and D. It can be seen in Table II that the total ferric oxide content of profiles

A and B is greater than that of profiles C and D. Several workers have suggested that free ferric-oxide could exert a protective action on the organic matter of the soil. The free ferric-oxide content of the clay fraction($<2\mu$) when determined by Drosdoff and Truog's (5) method for the surface horizons of profiles A, B, C and D was 4.1 per cent., 4.6 per cent., 1.83 per cent. and 1.64 per cent. respectively. This would substantiate the above claim, and it would receive further support since some protective mechanism has to be invoked to explain the survival of such levels of organic matter in the surface soils which have a mean maximum soil temperature exceeding 110°F during the dry season.



% Organic matter.

Fig. 7. Organic matter content of the profiles.

As seen in the results of Table II, profiles A and B show very little signs of chemical differentiation within the profile. There is evidence of a slight enrichment of the surface horizons in bases and P_2O_5 which is most likely due to the return of these elements to the surface by leaf fall. The total silica and sesquioxide contents show very little difference in value right down to the decomposing rock zone; pH values also show hardly any variation down the profile. Although there is considerable downward movement of water in these profiles, the chemical constituents appear to have attained an equilibrium condition whereby no further mobilization takes place.

Profiles D and E which show considerable mottling in the sub-surface horizons show definite signs of chemical differentiation within the profile. Enrichment of the surface horizons in bases is more pronounced than in the case of profiles A and B. The sesquioxide contents of profiles C, D and E is less than that of A and B. It is further observed that the sesquioxides appear to have been mobilized and deposited in the sub-surface horizons of the profile. Hydrological data in the earlier part of this paper have shown that the fluctuation in the water table occurs most frequently in the location of profiles C, D and E. Alternating reducing and oxidizing conditions that arise as a result of this fluctuating water table would promote the solution of iron and manganese which would get partly leached out in the receding water table, and partly precipitated in the form of concretions. pH values show a sudden rise in horizons where concretionary limestone occurs.

Total exchangeable cation contents of the upper soil horizons show no appreciable difference between the profiles. A detailed analysis for the fine earth of profile A (0-9″) is as follows :—

Exchangeable Cation		*M.e /100 gm.*
Ca	..	8.10
Mg	..	1.60
K	..	0.81
Na	..	0.06
H	..	4.30

In random studies carried out around the area, it is observed that there is considerable undulation of the quartz gravel horizon. Concentration of quartz gravel into a stone line has been attributed to the activity of the soil fauna in the case of some Ghana (Gold Coast) soils by Nye (13). In the case of the stone line observed in these soils it is difficult to attribute it solely to faunal activity. Occurence of well rounded quartz pebbles is indicative of more drastic forces. It seems probable that this stone line represents an older land surface on which has been unloaded further material from which the soils above the stone line have developed. A certain amount of activity by soil fauna is observed when the soil is moist. Little crumbs of finer textured material are deposited on the surface which have been formed from material translocated from the lower depths of the soil. Detailed examination of termite mounds show that considerable mixing of the surface and sub-surface material could result from the constructional activity of the termites.

In attempting to relate these soils to world soil groups, one encounters the difficulty that no satisfactory system yet exists for classifying these tropical soils. Anderson (3) has shown that some soils in the Kongwa and Nachingwea districts of Tanganyika belong

to the group which Milne (11) described as "Non-laterized Red Earths" and which also correspond to the "Rotlehem" of Kubiena (9). Soils of this group have a kaolinitic clay, precipitated iron oxides and do not form stable aggregates. The "Laterized Red Earth" of Milne (11) has a high proportion of secondary iron oxide and the soil is more or less permanantly aggregated. This group corresponds to the Russian "Krasnozem" and Kubiena's (9) "Roterde". On the foregoing considerations, it would be possible to fit the well drained members of the Dry Zone catena to the "Non-laterized Red Earth" group; the poorly drained members could be classified as "hydromorphic variants" of the "Non-laterized Red Earth".

CLAY MINERALOGY

X-ray diffraction powder and oriented flake techniques were used to determine the minerals of the clay fraction (less than 2 microns). The flakes were examined air dry and after treatment with glycerol, Mac Ewan (10).

The results of the mineralogical examination of the clays of profiles A, B, C and D are given in Table III. The chemical analysis of a few of these clay fractions is given in Table IV.

It can be seen from Table III that kaolinite is the predominant clay mineral in these soils. This is in accordance with similar studies on tropical soils where it has been generally observed that the end products of tropical weathering are usually kaolinitic clays. Jackson (8) in his postulates of the weathering sequence, assigns gibbsite and anatase to the extreme end of the weathering scale. In the humid tropical environments, this end of the weathering scale is attained in the old soils where gibbsite can be identified in the clay fraction. No trace of gibbsite was observed in any of the X-ray photographs of the clay fraction of this study. This is not surprising since the climate of the Research Station falls within the semi-humid monsoon regions of the tropics, where a well defined dry season alternates with a humid wet season. It can be seen in Table III that illite occurs indiscriminately in the different soil horizons; this may probably be due to the marked variation in the composition of the parent rock.

When studying the distribution of montmorillonite from Table III, it is observed that in profiles A and B, montmorillonite occurs mainly in the decomposing rock zone. In the profiles C and D, on the other

hand, montmorillonite occurs in the decomposing rock zone as well as in some of the sub-surface horizons. The general rules governing the type of clay mineral formed, though not comprehensively worked out, have shown that montmorillonitic clays are formed in areas of poor drainage, while kaolinitic clays are formed in areas of good drainage. Profiles A and B, which are at the higher aspects of the slope have good drainage throughout their depth, while profiles C and D have poor drainage, especially in the lower depths of the profile. Nagelschmidt et alia (12), have shown that in the tropics, small changes of relief are enough to give the change from red soils with kaolinitic clays in the well drained areas, to the black soils with montmorillonitic clays in the less well drained areas.

A further relationship that emerges from the present study, is the influence of drainage on the accessory soil colloidal minerals. It is observed in Table III, that the iron oxide mineral haematite is the chief accessory mineral of the well drained soils, while that of the poorly drained members is goethite.

The decomposing rock zone of profiles A, B and D is the seat of relatively early stages of weathering as borne out by the occurence of the clay minerals chlorite and vermiculite, which are not stable in normal soils. Further more the occurrence of montmorillomite in the decomposing rock zone of all the profiles is evidence of the residual nature of the soils. The higher temperature and stronger leaching of the surface horizons cause a greater degree of weathering than deeper down the profile. Hence the preponderance of kaolinite in the upper horizons of the profiles.

Summary

Soil profiles taken along a traverse from the watershed to the adjacent valley in a typical land unit of the Dry Zone have been studied in detail. The soils are derived mainly from charnockite rock. A catenary sequence of soils is recognizable. Hydrological studies indicate that differentiation of the member series of the catena is primarily conditioned by variations in drainage. Factors influencing soil formation and profile development are discussed.

Mineralogical studies show that the clay minerals are predominantly kaolinitic. The deeper horizons of the profile contain small amounts of montmorillonite ; illite occurs in some horizons ; the weathering zone is chiefly montmorillonite. Of the accessory minerals, haematite is the chief constituent of the Red Earths, whilst that of the poorly drained members is goethite.

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TABLE I.—Meteorological Data

		Jan.	*Feb.*	*Mar.*	*April*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*
Mean. Max. Temp. °F.	Average	83·3	87·0	91·2	91·6	90·8	90·0	90·8	91·4	91·8	89·0	85·8	83·2
Mean. Min. Temp. °F.	for	69·1	69·4	71·6	74·4	76·4	76·4	75·9	75·5	75.0	73·5	71·4	70·1
Mean. Rel. Humidity	12 years	81	74	73	76	76	71	70	68	68	77	81	83
Sunshine hr./day (1957)	..	8·5	8·8	8·9	9·2	7·1	6·9	7·6	10·7	7·5	6·9	5·2	5·8
Evaporation free-water surface, (inches) (1957)		4·41	4·70	8·43	7·20	5·72	6·43	8·43	9·86	10·01	6·33	2·81	2·76
Total annual evaporation ; 77·09 inches.													
Wind mileage/24 hrs. at 20 ft. ht. (Average for 5 years)	..	122	119	110	119	207	292	265	276	256	153	83	104

TABLE II—Soil Analysis*

Horizon Inches	Mechanical Analysis: Coarse Fraction % (4–0·2mm)	Fine Sand % (0.2–0·02mm.)	Silt % (0·02mm 2u)	Clay% <2u	CaCO3%	Organic Matter%	pH	Total Fusion Analysis: SiO_2%	R_2O_3%	AL_2O_3%	Fe_2O_3%	Mno%	TiO_2%	CaO%	Mgo%	Hydrochloric acid Soluble: P_2O_5%	K_2O%	Total exchangeable cations (m.e./100g)
Profile A																		
0–9	28·56	31·54	9·45	31·47	—	1·68	6·6	72·81	23·65	16·89	5·85	0·14	0·77	1·59	0·40	0·05	0·16	10·59
9–26	22·27	28·13	7·76	42·46	—	0·86	6·8	67·34	29·73	20·49	8·26	0·14	0·84	1·50	0·61	0·03	0·15	11·80
26–43	34·26	28·44	7·16	32·13	—	0·37	6·7	69·98	27·89	19·62	7·45	0·09	0·73	1·42	0·18	N. D.	N. D.	N. D.
43–57	40·97	44·89	6·60	8·41	—	0·03	6·9	62·70	28·25	20·69	6·80	0·15	0·34	4·62	1·03	N. D.	N. D.	N. D.
57–91	75·84	19·06	1·88	3·26	—	0·02	7·05	60·16	27·85	16·29	9·54	0·20	0·82	5·90	1·80	N. D.	N. D.	N. D·
Profile B																		
0–9	33·58	23·13	13·50	30·12	—	1·75	6·6	73·35	23·74	15·99	6·94	0·13	0·67	0·87	0·22	0·05	0·16	11·60
9–17	27·25	22·35	11·35	39·30	—	1·25	6·6	72·84	26·92	17·99	7·99	0·14	0·79	0·88	0·13	0·03	0·14	11·80
17–44	28·40	14·32	8·09	49·20	—	0·75	6·5	67·89	30·28	23·73	5·68	0·14	0·73	0·60	0·44	N. D.	N. D.	N. D.
44–62	44·90	10·83	11·05	34·14	—	0·42	6·5	70·91	25·36	21·04	3·92	0·06	0·32	0·45	0·21	N. D.	N. D.	N. D·
62–72	38·54	13·73	15·95	32·24	—	0·30	6·4	73·00	24·84	22·14	2·57	0·06	0·68	0·76	0·40	N. D.	N. D.	N. D·
72–90	48·53	31·02	10·10	11·02	—	0·15	6·55	70·90	23·69	19·19	4·34	0·03	0·14	2·78	0·36	N. D.	N. D.	N. D.
Profile C																		
0–7	39·26	24·50	8·59	27·84	—	1·10	6·4	78·23	19·83	13·70	5·40	0·04	0·68	1·06	0·36	0·03	0·09	10·00
7–29	38·36	24·40	6·68	31·27	—	0·55	6·9	76·41	19·93	13·54	4·88	0·07	1·44	1·14	0·27	0·02	0·07	10·00
29–70	40·86	13·68	9·64	35·82	—	0·25	6·9	77·11	20·79	14·99	5·40	0·07	0·33	1·00	0·44	N. D.	N. D.	N. D·
70–75	46·18	11·64	6·67	35·50	0·09	0·09	8·5	75·40	22·12	15·98	5·88	0·05	0·21	1·11	0·51	N. D.	N. D.	N. D.
75–91	47·85	12·52	9·83	29·50	0·69	0·07	8·8	74·19	23·87	21·92	1·76	0·02	0·17	2·31	0·46	N. D.	N. D.	N. D.
Profile D																		
0–7	47·53	28·31	6·48	17·82	—	1·12	6·6	82·83	12·30	7·48	4·07	0·08	0·67	1·19	0·38	N.D.	N.D.	10·50
7–20	44·40	28·67	8·15	18·67	—	0·50	6·95	78·84	14·95	9·43	4·99	0·03	0·50	1·77	0·28	—	—	12·46
20–36	36·72	20·63	5·95	36·31	—	0·33	8·2	76·51	17·64	11·12	5·87	0·21	0·44	1·29	0·69	—	—	N.D.
36–52	36·57	21·25	14·52	27·39	0·04	0·08	8·5	70·75	20·79	15·24	5·05	0·06	0·43	1·45	0·69	—	—	N.D.
52–75	49·06	27·31	4·90	17·95	0·78	0·02	9·1	68·24	18·82	12·51	5·86	0·06	0·39	3·56	1·49	—	—	N.D.
Profile E																		
0–4½	32·33	34·66	8·26	24·78	—	N.D.	6·5	76·18	17·03	10·90	4·89	0·16	1·09	2·25	0·26	N.D.	N.D.	N.D.
4½–18	22·72	33·99	6·75	38·27	—	N.D.	6·8	71·40	20·81	13·29	6·26	0·17	1·09	2·18	0·08	—	—	—
18–30	20·23	28·05	2·41	50·28	—	N.D.	6·35	69·88	20·04	16·13	6·20	0·13	0·59	1·99	0·02	—	—	—
30–39	32·03	19·21	7·84	41·03	—	N.D.	6·9	74·33	19·72	14·62	4·99	0·10	N.D.	1·54	0·26	—	—	—
39–69	45·81	29·96	6·84	17·34	0·10	N·D·	8·35	68·04	20·90	16·41	4·03	0·15	0·40	3·60	0·79	—	—	—

* Results expressed on over dry basis.

N.D. = Not determined.

TABLE III.—Mineralogy of Soil Clay (<2μ)

Profile and Depth	*Clay Minerals*			*Accessory Minerals*
	High	*Medium*	*Low*	
A. 0–9″	Kaolinite	—	—	Un-identifiable Fe_2O_3
9–26″	Kaolinite	Illite	Montmorillonite	Haematite
26–43″	Kaolinite	Illite	—	Haematite
43–57″	Kaolinite	—	Montmorillonite	—
57–91″	Montmorillonite	—	Kaolinite, Chlorite, Vermiculite	Quartz, Feldspar
B. 0–9″	Kaolinite	—	—	Haematite
9–17″	Kaolinite	—	—	Haematite
17–44″	Kaolinite	—	Illite	Haematite
44–72″	Kaolinite	Illite	—	Haematite
72–90″	—	Montmorillonite, Illite, Kaolinite	Chlorite, Vermiculite	Quartz, Feldspar, Haematite
C. 0–7″	Kaolinite	—	—	Goethite
7–29″	Kaolinite	—	—	Goethite, Haematite
29–70″	Kaolinite	Montmorillonite	—	Goethite
70–75″	Montmorillonite	Kaolinite, Illite	—	Goethite
75–91″	Montmorillonite	Kaolinite	—	Calcite
D. 0–7″	Kaolinite	Montmorillonite	—	Goethite
7–20″	Kaolinite, Montmorillonite	—	—	Goethite
20–34″	Kaolinite, Montmorillonite	—	—	Goethite
34–38″	Montmorillonite	Kaolinite	Illite, Chlorite, Vermiculite	Quartz, Feldspar
38–75″	Montmorillonite	Kaolinite	—	Quartz, Feldspar

TABLE IV.—Chemical Analysis of Clay Fraction*

Profile	*Depth*	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	MnO
A	0–9″	53·47	32·56	9·88	0·68	0·16
	9–26″	52·47	35·51	10·10	0·63	0·11
	26–43″	48·84	35·06	8·52	0·66	0·10
	43–57″	51·76	29·99	8·09	0·36	0·13
	57–91″	53·52	22·38	11·23	0·06	0·03
B	0–9″	47·27	31·16	15·12	0·79	0·12
	9–17″	48·29	27·72	15·56	0·75	0·11
	17–44″	48·78	27·54	14·69	0·57	0·10
	44–62″	50·60	32·68	12·13	0·52	0·08
	62–72″	50·85	38·42	4·42	0·02	0·07
	72–90″	56·26	34·24	5·20	0·11	0·05
C	0–7″	51·68	36·58	12·09	0·99	0·12
	7–29″	50·51	37·14	5·84	1·10	0·14
	29–70″	52·80	29·75	7·84	0·88	trace
	70–75″	55·24	22·27	10·58	0·98	trace
	75–91″	56·69	23·70	8·58	0·38	trace

(* Results expressed as per cent. of ignited clay.)

WEED CONTROL PROBLEMS IN THE DRY ZONE*

By

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A VITAL FACET of Dry Zone agriculture that had received scant attention until recently, was the control of weeds. Since the Maha 1956/57 however, it has been subjected to more intensive study at Maha Illuppallama. While the progress made so far has not been remarkable, it has nevertheless been possible to arrive at certain broad generalizations pertaining to weed control in the commoner highland crops of the dry zone.

From the point of view of weed control it is necessary to recognize two components in the pattern of Dry Zone agriculture ; one is the production of irrigated paddy, and the other, the production of unirrigated or highland crops which includes cereals, pulses, fibres and pastures. The weed problems in the two are distinct, and are therefore considered seperately.

Weed Control in Irrigated Paddy

The conditions under which irrigated paddy is produced are essentially the same all over the Island. While there are differences between the dry zone and the rest of Ceylon so far as soils, climate, varieties, &c., are concerned, regarding weed control, the most important difference between a dry zone and a wet zone paddy field for example, is likely to be seen in the composition of the weed flora. In spite of these differences however, the methods that would have to be adopted to control weeds in Dry Zone Irrigated Paddy are not likely to differ greatly from those for a wet zone field. In this light, weed control in irrigated paddy is not strictly a local problom of dry zone agriculture, but one, rather more universal.

No detailed experiments have so far been carried out at Maha Illuppailama on weed control in irrigated paddy, and hence this aspect of dry zone agriculture will not be dealt with in any detail. Nevertheless, a few general statements will not be out of place.

* Contribution No. 6 from the Division of Dry Zone Research.

Observations on the weed flora in a dry zone paddy field show that it does not differ greatly from that in the wet zone. While species like *Echinocloa colonna, Isachne australis* and *Panicum repens* are common to paddy in all parts of Ceylon, certain wet zone species like *Coix gigantea, Salvinia auriculata* and *Eichornia crassipes,* occur rarely, if at all in the dry zone ; on the other hand, *Jusseia suffructicosa* and *Acanthus ilicifolius* seem to be more prevalent in the dry zone, the former in the growing paddy and the latter in the off season among the stubble.

There are two standard techniques of growing a crop of irrigated paddy, namely transplanting and broadcasting ; such modern innovations as the Japanese method and row sowing are merely variations of these. From the point of view of weed control, broadcasting is the least satisfactory of these various techniques, because in such a crop, a large proportion of the weeds are not removed by any of the mechanical methods of weed control commonly advocated for irrigated paddy ; these include hand pulling, harrowing the standing crop and the use of a Japanese rotary hoe, and they are still the most popular means of weed control in irrigated paddy.

Lack of experimental data makes impossible any definite comment on the chemical control of weeds in Irrigated Paddy. Any work on the practical application of weedkillers in this crop must however take into account the reportedly excellent results obtained so far with the rotary hoe in row sown and transplanted paddy. Until such time as the relative merits of this implement and the various weedkillers are fairly assessed, it would be imprudent to insist on the use of the latter.

Weed Control in Highland crops

Whereas irrigated paddy is produced under almost identical conditions in all parts of the Island, highland cultivation in the dry zone is distinct from that, say, in the wet zone. In striking contrast to the mixed gardens of the latter which carry such perennials as Artocarpus, Areca, &c., the unirrigable high lands in the dry zone are annually cropped with a variety of cereals such as kurakkan, highland paddy and maize, and also, non-cereals like gingelly, chillies, green gram and cotton. The peculiar rainfall distribution in the dry zone has contributed most to the development of this tradition of highland cropping with annuals.

The natural conditions of the dry zone and various other aspects of modern dry land farming are reviewed in detail by Abeyratne, (1956). Only the weed problem facing dry zone agriculture will therefore be presented here.

Highland cultivation in the Dry Zone takes place mainly in the Maha with the onset of the rains in October. Preparatory tillage begins with the first rains, and sowing of the major crops like kurakkan, maize and highland paddy and cotton is completed by the end of the month ; sorghum, pulses and ground nuts are generally sown in November ; and all the crops are harvested in February and March.

A diversity of weeds infests the crops throughout the season. The end of the first fortnight in October sees the freshly prepared 'clean' seed beds covered with a mantle of green weed seedlings ; the earliest sown crops have by them only just begun to germinate, and a crop left unweeded by at least the end of the third week gets rapidly smothered.

The majority of the highland weed species are annuals. The most prolific and widely disseminated of the dicotyledonous species that generally infest the crops are *Acanthospermum hispidum, Euphorbia geniculata, Boerhavia sp : Mitracarpum villosum, Ocimum americanum, Sida Acuta, Ipomoea sp : Gomphrena decumbens; Vernonia cinerea, and Aeschynomene indica ;* besides these, there are numerous other annual dicotyledonous weeds that are found more often in the borders, bunds and wastelands. Compared with the dicotyledons, the list of annual grass weeds is not impressive ; foremost among these are *Echinocloa colonna, Dactyloctenium aegyptiacum, Digitaria ascendas, Eragrostis viscosa, Chloris barbata,* and *Cenchrus echinatus.* However in terms of the universality of their distribution and the density of their numbers, the grasses easily outstrip the dicotyledons ; and in fact present a more serious challenge to the growing crop than the latter class of weeds.

Perennial weeds do not occur in such great variety as the annuals ; the annual tillage and cropping of the cultivated highlands has helped to confine them to the bunds, roadsides and wastelands. In these uncropped areas, the perennials do not pose any serious problem to the cultivator, and it is probable that they actually serve a useful purpose by affording an excellent cover against erosive forces. There is however one perennial weed, *Cynodon dactylon,* which has covered extensive areas of otherwise cultivable land ; this weed has set a special problem of weed control.

The tough rhizomatous *Cynodon* has so far defied all attempts of mechnical control ; such methods have in the long run only helped to multiply the weed vegetatively by cutting up and spreading the perennating rhizomes. In small localized patches the plant is easily killed off by fairly heavy applications of chemical weedkillers such as TCA (2, 3, 6—trichloroacetic acid), and Dalapon (2, 2—dichloropropionic acid), but when it comes to a question of acres, the cost of the

4——J. N. R 2194 (5/59)

chemical makes this method of control prohibitive. Furthermore, over a large area, a machine mounted sprayer becomes essential so as to apply the chemical uniformly. Even if this capital outlay could be afforded, there is also the problem of chemical residues in the soil to be considered ; TCA persists longer in the soil than Dalapon, but in either case, it is more than likely that the land would be uncultivable for at least one season after the treatment. A final point that arises in the use of these chemical to eradicate *Cynodon* is whether the crop that is to follow will repay the money expended. The control of *Cynodon* in agricultural land thus resolves itself into a problem of land management.

The control of a perennial weed like *Cynodon* is relatively static compared with the problem of weed control in a growing highland crop. Here, the operation becomes a dynamic one, with the cultivator striving to suppress one group of plants while at the same time attempting to nurse another, both of which are competing for a limited supply of light, water, mineral salts and air.

The earliest experiment on weed control in a highland crop is reported by Abeyratne (1956) ; it was shown that the crop responds best to a weeding given within the first week from germination ; two subsequent weedings at 10-day intervals were sufficient to complete the routine. Due, however, to the heavy rains at the beginning of the *Maha* and the ease with which the dry zone soils get saturated, such a program of operations is not always possible ; thus alternative avenues of weed control have had to be explored. The choice fell on the use of chemical weedkillers and subsequent experiments have always involved the use of these materials.

Chemical weedkillers can be applied in either of three ways :—

(*a*) Pre-Sowing, where the chemical is applied anything from three months to even one day before sowing.

(*b*) Pre-Emergence, where the chemical is applied after sowing, but before the seed germinates, and thirdly.

(*c*) Post-Emergence, where the chemical is sprayed on the standing crop.

The first method is usually employed with chemicals that have a pronounced residual effect in the soil and act as temporary soil sterilants. Application long before sowing helps any toxic residues to be leached away. But, since in the dry zone the months immediately preceding the *Maha* are for all purposes rainless, pre-sowing application of chemicals cannot be considered a practical proposition for this region.

Pre-emergence chemical weed control has given the most promising results so far in the course of two seasons' experimentation. Its most attractive feature is that it helps to keep the seed bed free of weeds during the critical early stages of growth. Ideally, the use of a pre-emergence weedkiller should eliminate the need for any subsequent weed control measures. But, because the commonly available pre-emergence weedkillers are only selectively toxic to the dicotyledonous weeds, it has been necessary to combine their application with post-emergence mechnical treatments to get rid of the grasses that survive. The earliest experiments on such combined methods of weed control are described in another paper, Kirinde (1957). Table I summarizes the results of such experiments carried out during the seasons *Maha* 1956/57 and 1957/58.

While Table I in no way claims to represent the ideal treatments for the crops shown therein, it yet reveals the following :—

(*a*) A consistent increase in yield in response to weeding in one form or another.

(*b*) The use of a pre-emergence weedkiller alone is hardly worthwhile, but followed by at least two mechanical weedings it gives satisfactory results.

(*c*) There is no great difference between the two chemicals employed, both of which are chemically related and belong to the class of ' Contact Herbicides '.

Other crops that have been tested out with pre-emergence chemicals are kurakkan and groundnuts ; the latter responds well to both DNBP and PCP, while the former does not. The drawback in the use of DNBP and PCP is that they exhibit mammalian toxicity, especially at high temperatures, and are also unsuitable for low-volume application, a fact of importance in the dry zone, where water is scarce. Experiments with other weedkillers to test for their pre-emergence value are still in appreliminary stage.

The final method of chemical weed control is by post-emergence application in a standing crop. Experiment has shown that this method has an important limitation in the dry zone highlands. Although the annual weed flora is extremely heterogeneous, the fact that the grasses from its main component makes the post-emergence application of selective weedkillers especially in the cereals, rather limited in its scope. In irrigated paddy on the other hand, where it is impossible to carry out a pre-emergence application, this method is likely to be of greater value ; before any practical recommendations are made however, detailed and precise experimentation is necessary to establish the safest times and levels of application.

5——J. N. R 2194 (5/59)

Conclusion

The foregoing has been in the nature of a general survey ; not every aspect of weed control in the dry zone has been touched upon ; for example no mention is made of such crops as sugar cane and pastures, both of which are currently gaining importance in the region. The survey has in the main been concerned with the commoner annual highland crops.

Nor is mention made of the effect of various herbicides under specific dry zone conditions ; for, herbicides can be studied from the point of view of either their action on particular plants under various environmental conditions, or, their suitability for incorporation in the routine agricultural practices of any given region. The latter has been more the view in the studies carried out at Maha Illuppallama so far, although some information of the former has also been gathered in passing.

While the scant experimental results obtained to date are not greatly impressive, they yet reveal the potentialities of weed control in augmenting the agriculture output of the dry zone. But weed control in general can take either of two aspects : it can be refined or crude. The latter is associated with low standards of arable farming and is carried out in a haphazard manner, as and when the farmer feels free to do so. The essential feature of the former is that it is an integral part of the routine operations in crop production—the land is tilled, the seed is sown and weed control measures are adopted at pre-determined times. In this respect, contemporary weed control in the dry zone cannot be described as refined in any degree.

As regards improved techniques of weed control for the dry zone, it must be remembered that the use of chemical weedkillers is an advance from the systematic employment of mechanical means. The farmers in western countries were already aware of the benefits accruing from systematic mechanical weed control and were thus ready to grasp the full implications in the use the hormone weedkillers as soon as they were introduced. In comparison, the dry zone farmer is an impoverished and rather ignorant individual, trammelled by convention, prejudiced and superstitious. His only weapons against weeds have been the mammothy and fire, and when these are impossible to wield he retreats into another chena. Hence the basic idea that should be stressed in the dry zone today is the need for systematic weed control as such, rather than the need to use a particular chemical. Such an approach may seem rather slow to some people, but its importance is emphasized on considering that the maximum benefits of

systematic weeding are acquired only under a high standard of cultivation, such as the use of pure seed, correct fertilizers, &c. The actual date on which chemical weedkillers will be in popular use in the dry zone may thus lie several years in the future. The studies being carried out now are to be in readiness when that time arrives.

Summary

There are two distinct aspects of weed control in the dry zone, that in irrigated paddy, and that in the unirrigated, annual highland crops. But the problems in the former are not strictly problems of dry zone agriculture, because the conditions under which irrigated paddy is produced are practically the same in all parts of the Island.

A large number of annual dicotyledonous and grass species go to form the highland weed flora. It is the grass component, however, that offers more serious competition to the growing crop. The only perennial weed of importance is *Cynodon dactylon*, which has spread to such an extent as to create a special problem of land management.

Of the various methods of highland weed control, the best appears to be the use of a pre-emergence chemical followed by two or three mechanical weedings; this operation achieves the triple function of giving early weed free growth, eliminating the dicotyledons and eradicating the grasses.

Since contemporary husbandry practices in the dry zone are not of a very high standard, the fundamental aim should be to impress on the cultivator the benefits of weed control as such, rather than insist on the use of any particular chemical.

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TABLE I.—The effect of various methods of Weed Control on the Yields of some highland crops

(Average Yields in lb. per acre)

CROP	*MAHA*	*Mechanical Weedings only*			*Pre-Emergence sprays only*		*DNBP + Two Weedings*	*Pre-Emergence sprays + Mechanical Weedings*	
		None	*Two*	*Three*	*DNBP**	*PCP**		*DNBP + Three Weedings*	*PCP + Three Weedings*
Sorghum	56/57	375	1,650	2,230	1,230	—	2,030	2,340	—
Highland Paddy	56/57	18	—	790	200	—	—	1,390	—
Highland Paddy	57/58	600	—	2,860	520	520	—	3,060	3,120
Maize	57/58	500	—	1,600	720	600	—	1,820	1,920
Cotton	57/58	23	—	345	13	12	—	780	607

Note.—

* DNBP (2, 4—dinitro—6—sec.—butylphenol) ; 1.0 gal : 1.7 % formulation per acre.

* PCP (pentachlorophenol) ; 2.0 gal : 1.2 % formulation per acre.

All mechanical weedings at 10-day intervals, commencing 10 days from sowing.

GRASSLAND FARMING IN THE DRY ZONE *

By

G. W. E. Fernando

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ECONOMICS of dry land farming had hitherto fluctuated between extremes of profit and loss in consequence of the erratic rainfall. The advent of grassland farming marks a distinct change in this relationship. In contrast to most highland crops, grass shows better adaptation to extremes of rainfall distribution. Meteorological records indicate that a normal year seldom occurs, and a good cropping season in one year may be followed by a complete failure in the next.

The development of pastures in the dry zone becomes desirable from the social, economic and agricultural standpoint on account of the contribution that animal husbandry would make to:

(*a*) correcting the deficiency of protein in the diet of the dry zone peasant;
(*b*) creating a stable rural economy; and
(*c*) maintaining the production potential of the land.

In the dry zone's pasture improvement programme it is necessary to determine the adaptative possibilities of grasses, their methods of establishment, and their reaction to grazing and cutting. Equally important is the search for promising pasture species and a study of their carrying capacity and nutritive value. This paper reviews the progress achieved at Maha Illuppallama during the last two years and seeks to provide some information on the pasture potential of the dry zone.

The Environment in the Dry Zone

The dry zone environment shows certain well defined characteristics:

(1) a bimodal rainfall distribution (the average monthly rainfall and the maximum and minimum temperatures are given in Table I);

* Contribution No. 7 from the Division of Dry Zone Research.

(2) A marked dry season from June to September with no effective rainfall and accompanied by strong dry winds ;

(3) the existing natural vegetation which though arboreal also has a pasture component.

Table I—Weather Conditions in the Dry Zone

	Jan.	*Feb.*	*Mar.*	*Apr.*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*	*Total*
Rainfall Average for 50 years	5·5	1·9	4·6	7·2	4·2	1·3	1·5	1·6	3·0	9·4	10·0	8·0	58·2
No. of wet days	10	4	7	10	5	3	3	3	6	15	17	13	96
Mean Max. °F.	83·5	87·5	92·0	91·3	90·2	90·1	89·6	90·8	91·2	88·1	85·6	83·0	—
Mean Min. °F.	69·3	68·5	71·5	73·9	76·3	76·1	74·9	75·2	74·7	73·3	70·5	70·0	—

Pasture Improvement

The dry zone presents two distinct fields of pasture improvement. The first is the improvement of natural pastures by correct methods of management, and the second is the establishment of artificial pastures by the provision of more productive strains of grasses and legumes.

Natural Pastures

The natural pastures of the dry zone are confined to road sides, tank beds, fallow paddy fields, scrub jungle, parklands and "villu" grasslands. The most important for grazing purposes are the more or less homogeneous parklands and "villu" grasslands, along the Mahaweli and its tributaries in the Tamankaduwa district. The parklands represent vegetation in various stages of succession ; the grasses chiefly consists of *Chrysopogon* spp., *Eragrostis* spp. *Aristida setacea* and *Paspalidium flavidum*. In the shade, *Stenotaphrum dimidiatum* and *Cyrtococcum trigonum* are dominant. Other commonly occurring grasses are *Cynodon dactylon, Chloris barbata* and *Dactyloctenium aegyptium*. The associated legumes are *Alysicarpus vaginalis* and *Desmodium triflorum*. The "villus" or the flood plains of the anastomosing streams of the Mahaweli are covered by dense swards of waterloving grasses, which show different degrees of adaptability to water-logging. The grasses are chiefly species of *Sacciolepis* and *Paspalam* and *Brachiaria mutica*.

Most of the naturally occurring grass species are generally low yielding, poor in quality and are unproductive for most parts of the year. The dry season is characterised by a shortage of fodder in natural pastures, so that the cattle will have to feed on withered grasses for a few months before the rainy season. Generally, the cattle move towards moist regions, around tanks and irrigation channels for their grazing. On the whole natural pastures have a lower carrying capacity than introduced pastures, and the low productivity does not permit adequate conservation in the form of hay or silage. These native pastures can be made more productive by the sowing of high yielding and nutritious species of herbage plants or by a system of controlled grazing which will prevent severe overgrazing and deterioration.

Establishment of Grazing Areas

The greatest pasture potential of Ceylon is in the dry zone, where land is not a limiting factor for extensive grassland farming. There are approximately 2.6 million acres of uncultivated land which are available for future agricultural development. Land utilization research and soil classification studies indicate the presence of a distinct land class suitable for pasture establishment in every dry zone catchment. (1)

The absence of natural pastures with the exemption of parklands, villus and similar areas in the dry zone, compels the stock farmer to clear the forest for establishing grazing areas. The problem of establishment and maintenance of introduced pastures can only be discussed in terms of the species of grass that are presently in use. In order of importance, the pasture, soilage and silage grasses in the dry zone are :

(1) *Brachiaria brizantha* (Signal grass).

(2) *Pennisetum purpureum* (Napier grass).

(3) *Panicum maximum* (Guinea grass).

(4) *Brachiaria mutica* (Water grass).

Brachiaria Brizantha

Brachiaria brizantha is one of the highest ranking pasture grasses in Ceylon, largely due to its ability to survive long spells of dry weather. There are numerous ecotypes of *Brachiaria brizantha* of which the prostrate types have given better results than the semi-erect types.

Only a negligible percentage of the seed is viable, and therefore propagation by cuttings is obligatory. When fertilized adequately (2 cwt sulphate of ammonia and one cwt of basic slag) it produces annually about 8,000 to 10,000 lb. of dry matter per acre. The chemical composition of *Brachiaria brizantha*, cut at monthly intervals, is shown in Table II. *Brachiaria* makes good hay and silage for dry season use. The wide range of adaptability, high productivity, good reaction to grazing and cutting makes *Brachiaria brizantha* our foremost pasture grass in the dry zone.

Brachiaria brizantha pasture at Maha Illuppallama.

Pennisetum Purpureum

Napier grass grows luxuriantly under a wide range of climatic conditions and is suited for both wet and dry zones of the Island. It stands up to drought better than most other grasses. In Ceylon it is grown mainly for soilage but recent research indicates that it could be used for grazing as well. Indiscriminate stocking and grazing reduces plant density and leads to the encroachment of undesirable weeds. It is palatable, and would be completely consumed even if fed at a late stage of maturity. The quality of this herbage can be further improved by sowing *Stylosanthes gracilis* or *Pueraria phaseoloides* between rows of Napier. It is propagated by stem cuttings. Its resistance to drought makes it a promising fodder grass in the dry zone.

Panicum Maximum

Panicum maximum is a popular grass in the wet zone of Ceylon. It is not so drought resistant as Napier, but it produces an abundance of forage during the rainy season. It is mainly used for soilage. Guinea grass may be propagated from seed or cuttings. The latter is the only one by which a good stand can be assured since the viability of the seed is very low.

Brachiaria Mutica

Water grass is particularly suitable under special edaphic conditions. Its cultivation is limited to swampy areas, banks of streams and bottomland.

Chloris gayana Cenchrus ciliaris, Panicum coloratum, Panicum maximum var. *trichoglume* and *Paspalum commersonii* are some of the introductions under trial at the Dry Zone Research Station, Maha Illuppallama.

Grass and Legume Compatibility

The introduction of protein and calcium rich legumes in the grass sward to improve the quality of the herbage is a well known practice. So far, the maintenance of a proper balance of grasses and legumes has been particularly difficult, largely due to the rapidity with which weeds and grasses grow in the dry zone in the wet season. The planting of pure legume strips and the provision of leguminous foddersin pastures appear to be a satisfactory solution to this problem. The species under observation at the present time include *Alysicarpus vaginalis, Stylosanthes gracilis, Pueraria phaseoloides* and Centrosema *pubescens.*

Production and Chemical Composition of Pasture Herbage as Influenced by Season

The distribution of rainfall in the dry zone is markedly seasonal. There is a major wet season from October to January followed by a short dry spell in February and early March. Again, April is a wet month, followed by a marked dry season from June to September,

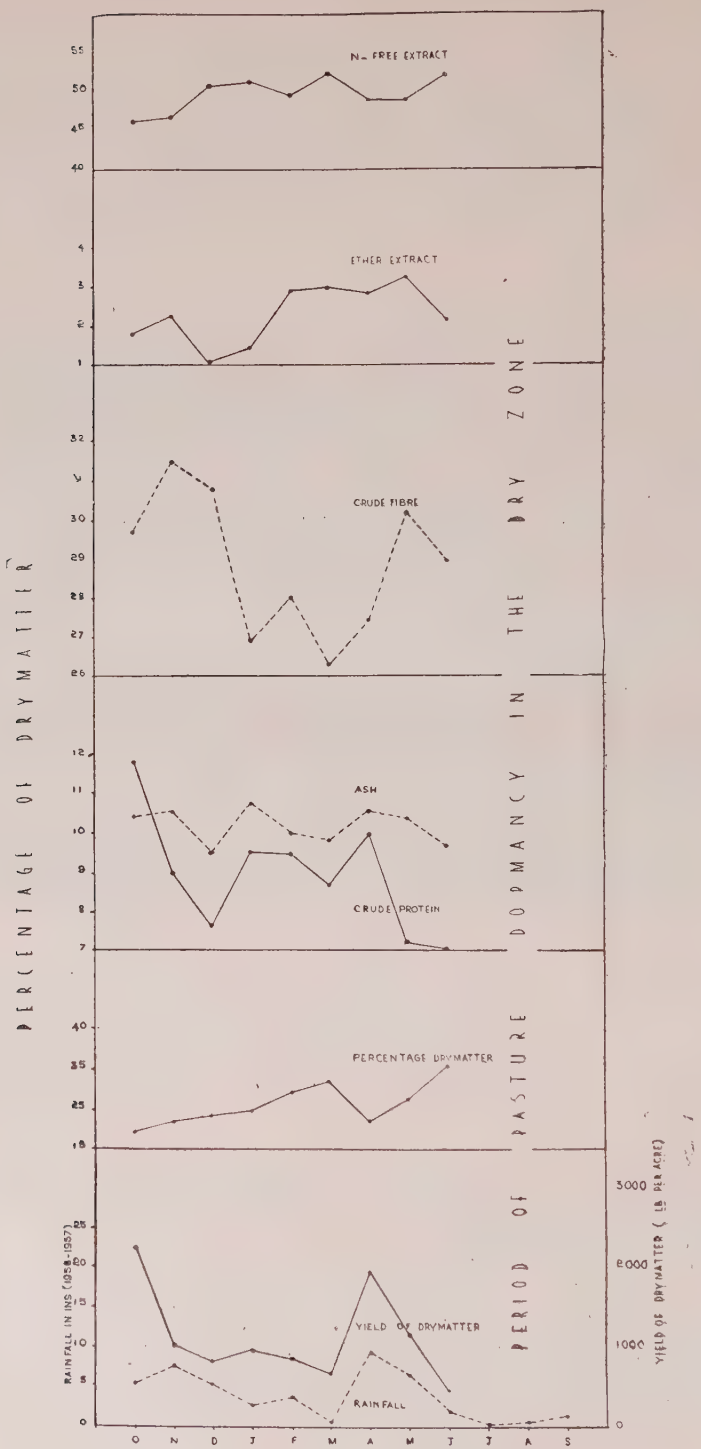


FIG. 1 SHOWING THE EFFECT OF SEASON ON YIELD AND CHEMICAL COMPOSITION OF A BRACHIARIA BRIZANTHA PASTURE IN THE DRY ZONE

which is essentially the period of pasture dormancy in the dry zone. The rainfall in 1957 was unique in its distribution. Of a total rainfall of 98.39 inches, which is over one and half times the average annual rainfall, 43.38 inches of rainfall fell in December alone.

The accumulated data during the last two years merits a more detailed discussion, in regard to fluctuations in yield and chemical composition of pasture herbage with season. Examination of Table II and Fig. 1 reveals that the quantity and quality of herbage are appreciably influenced by seasonal changes.

Pasture Production

Pasture growth in the dry zone follows a bimodal distribution, coincident with rainfall. In pastures, there is a flush period in October and November followed by a slower but steady vegetative growth in December and January. With the *yala* rains in April, there occurs a second growth period which is followed by a period of restricted growth in May and June, and the final drying off of pastures with the advent of the dry weather in July. During the peak period in October and April, pasture production exceeds the requirements of stock. This fact can be used to good effect in levelling fodder production and offering facilities for adequate herbage conservation in the form of hay and silage.

Table II—The effect of season on yield and chemical composition of *Brachiaria brizantha*

	Rainfall in. 1956–57	Green Material lb./ac.	Dry Matter lb./ac.	Percentage of Dry Matter					
				Dry Matter	Crude protein	Ash	Crude fibre	Ether extract	N-free extract
Oct.	5·20	11534	2253	19·4	11·84	10·49	29·78	1·83	46·06
Nov.	7·20	4813	1015	22·9	9·08	10·59	31·47	2·25	46·61
Dec.	5·08	3653	813	23·2	7·63	9·54	30·90	1·09	50·84
Jan.	2·63	3982	969	24·1	9·59	10·80	26·97	1·45	51·19
Feb.	3·33	3318	878	29·0	9·53	10·01	28·13	2·92	49·41
Mar.	0·42	2886	666	32·1	8·76	9·88	26·24	3·01	52·11
Apr.	9·23	8805	1966	22·3	10·06	10·66	27·51	2·83	48·94
May	6·65	4402	1122	27·5	7·21	10·46	30·21	3·27	48·85
Jun.	1·18	1160	410	36·8	7·15	9·73	29·15	2·18	51·79
Jul.	0·10	Period of Pasture Dormancy							
Aug.	0·12								
Sep.	1·51								
Total	42·65	44553	10092	—	—	—	—	—	—
Mean	—	4950	1121	26·4	8·98	10·24	28·93	2·32	49·53

Chemical Composition

Percentage dry matter: The dry matter content shows definite seasonal changes which are of considerable interest. The dry matter content risen steadily during dry periods of March and June, and drops sharply in the wet season. These variations markedly influence the intake of nutrients by the grazing stock at different times of the year.

Crude Protein and Minerals

Seasonal changes in the protein content of herbage are also pronounced. The protein content of the pasture is distinctly higher in October than in November, drops sharply in December, followed by a rapid increase in January and February. The protein content shows an increase in April as well and during periods of limited growth or when the pasture dries off the percentage protein falls abruptly. The variations in the ash content are strikingly parallel with those of protein. This it will be seen that wet weather which greatly increases productivity, also improves the quality of grass.

Crude fibre

The crude fibre percentage increases during the wet weather and decreases during the dry period.

Fats and Carbohydrates

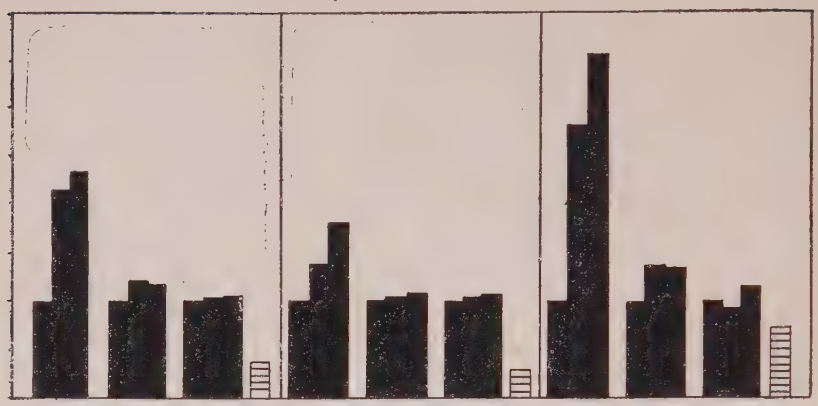
The data indicate that the fat content is relatively low during the wet season, but rises steadily from February onwards, and in May it is as high as 3.27 per cent. The lowest percentage, 1.09, is recorded in December. The carbohydrates show no significant seasonal variation.

The Use of Fertilizers

Nitrogen. Under conditions of grazing the ultimate influence of either the legumes or added nitrogen fertilizer is magnified by returns of nitrogen to the sward in the dung and urine of the grazing animal, when several fertility cycles may occur in one grazing season. It is reasonable to assume that these cycles from sward to the grazing animal and back to the sward are greatly accelarated by mixed stocking. Under conditions where the herbage is cut and carted off the field, the picture is very different. Here considerable quantities of nitrogen are removed from the field and further growth of herbage depends, amongst other things, on fresh supplies of available nitrogen. It has been estimated that under these conditions a Bracharia pasture removes annually from the soil approximately 100 lb. nitrogen per acre, equivalent to 4½ cwt. of Sulphate of Ammonia. In the absence of grazing stock, it is essential that this quantity of Nitrogen must be returned to the sward, for further production depends on further application of fertilizer nitrogen.

A more comprehensive study of this subject has been reported in a previous paper (2). The results gathered during the two year period are shown in Fig. 2. As none of the fertilizer interactions proved significant, only the main effects are shown. It will be seen that *Bracharia brizatha* responds markedly in dry matter yield to fertilizer nitrogen, but the responses were by no means proportional to the quantity of nitrogen applied. The application of heavy doses of nitrogen may be largely wasted on account of leaching during the *maha* season, the period of heavy rainfall. In 1956-57 when the rainfall was evenly distributed and not excessive, measurable residual effects were obtained at both levels of nitrogen application. However, when the rainfall was very excessive, as in the *maha* season of 1957-58, no residual responses were obtained, for any level of fertilizer nitrogen. There seems little justification for using heavy doses of fertilizer nitrogen if high productivity is the ultimate aim. But on the other hand, a high crude protein content

1956–57 Results



$N_0N_1N_2$ $P_0P_1P_2$

1957–58 Results

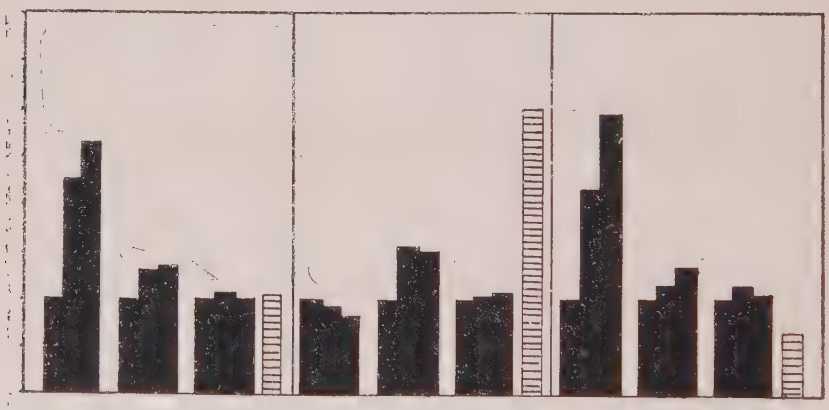


Fig. 2. Effect of fertilizers on dry matter yield of *Brachiaria brizantha* and the rainfall for separate harvests.

is desired, then the application of heavy doses of nitrogen seems justified from the results given below :—

Levels of Nitrogen	*Per cent Crude protein (Mean of 3 harvests)*
No nitrogen	6.74
40 lb. N/acre	8.03
80 lb. N/acre	10.53

Phosphates. As reported earlier (2) the available P_2O_5 content of this soil type was relatively poor and under these conditions one must anticipate higher yields to phosphates when it has been applied. Good grass swards cannot be maintained without an adequate supply of phosphate and its presence in sufficient quantity is also essential for the maintenance of quality. Phosphate is particularly important in the nutrition of legumes. Grasses in general do not show spectacular responses to phosphates. However in the absence of suitable legumes in our pasture, its application should rarely exceed 2 cwt. per acre.

Potash. The soils of the dry zone are generally well supplied with potassium. These experiments failed to show any yield responses to application of potash. Thus potash fertilization does not appear to be warranted under most conditions.

Studies in Grazing Management

In recent years, the principal trend in pasture management is towards rotatoinal grazing. Rotational grazing has been widely advocated as beneficial on the grounds that continuous grazing is injurious to pasture plants because of the sustained defoliation and that rotational grazing increases yields of both herbage and valuable nutrients. It has been shown (3), however, that rotational grazing cannot be accepted as a worth while practice in all environments. Grazing trials at Maha Illuppallama showed the following trends :—

1. The mean live-weight gains of heifers were 0.90 lb. and 1.11 lb. per animal per day for rotational and continuous grazing respectively.

2. Rotational grazing resulted in better utilization of the grass sward in that pasture was grazed more uniformly.

3. The most important factor in grazing management in the Dry Zone is likely to be the stock carrying capacity.

Under dry zone conditions, the stocking rate varies with the seasonal variations which in turn control the pattern of pasture growth. Therefor the rate of stocking should be closely adjusted to growth of

pastures. During the peak periods of growth, the pasture should be heavily stocked with a corresponding reduction in the dry season and this enables the stock to cope more adequately with flush production.

Attempts have been made to explore the possibilities of extending the grazing season by suitable management practices and the results achieved, so far, are of considerable interest. By means of drought resistant species, proper fertilization and proper stocking, it has been possible to conserve the herbage in situ for dry weather consumption. This implies that the quality of grass, as a food will be appreciably reduced but as shown in Fig. 3 the heifers continued to gain in weight during the dry period despite a total rainfall of 3.0 inches in the interval between 30th May and September 16th, 1958. No supplementary food was given at any time except 2 oz. of mineral mixture per animal per day.

Frequency of Sward Defoliation

The frequency of defoliation by cutting or grazing, is a factor which exerts a major influence on the yield, botanical and chemical composition of a pasture. It is proposed to make these, the subject of a separate paper and only a broad outline of the results are presented here.

Studies on the frequency of cutting *Brachiaria brizantha* confirm the well known increases in yield while the proteins and minerals in the dry matter show a gradual decline as herbage grows to maturity. Coincident with the fall of proteins and minerals is a rise in the crude fibre which undoubtedly means a fall in the digestibility of grass as a food. The optimum utilization of proteins and minerals is found to be at the 4th and 5th week intervals of cutting and rotational grazing of a Brachiaria pasture at these intervals may therefore be recommended.

Problems related to Grassland Farming in the Dry Zone

Lack of rainfall during July, August and September does not permit grazing on an all the year round basis. The shortage of grass during this period presents a major problem. Therefore, fodder conservation in the form of hay and silage is necessary to tide over periods of low herbage production. In the dry zone, an obvious source of conservable fodder will be the surplus production of green herbage from pastures during the peak periods.

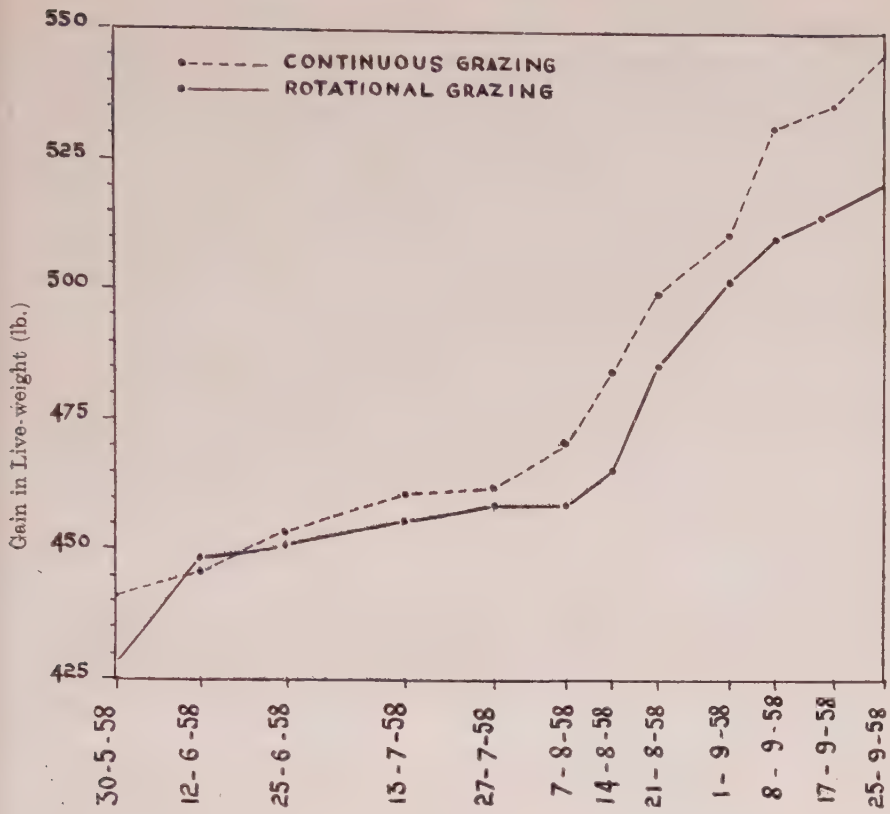


Fig. 3. Changes in live-weight during the dry season.

The advantages of preserving green fodder as hay or silage for use during the dry season are widely recognised. The two traditional methods of fodder conservation commonly practised are the making of hay and silage. Climatic differences have a marked influence not only on the choice of grass species, but also to a much greater degree on the harvesting, curing and storing of the hay crop. The production of hay is particularly difficult on account of heavy rainfall and high humidity that prevail during the *maha* season. Wet weather will rapidly destroy the hay crop, since the material contains nutrients that are easily dissolved by water and so readily washed out during rain. Excessive drying should be avoided as it causes shattering and loss of valuable leafy portions of the plant. Some good hay can always be made with the advent of dry weather in January and May. Silage making, on the other hand, is not only a better form of

conservation under our conditions but is also much more compatible with good pasture management. Trials at Maha Illuppallama indicate that good quality silage can be made only from material which has been cut and stored in a fresh green state, the aim being to conserve the fodder in a succulent condition. This is brought about by acid fermentation which occurs when the air is excluded from the silage mass. The best quality silage is light brown to yellow brown in colour, and possesses a distinctly pleasant acid smell. Silage of this kind can be made from suitable types of crops such as *Brachiaria brizantha,* Napier and fodder sorghum. If the crop is cut at an advanced stage of maturity or left to dry out in the field after being cut, normal fermentation will not occur, moulds will develop, and an inferior silage known as 'mouldy' silage will be the result. The addition of sugar molasses at the rate of two gallons per ton of green material not only improved the quality but also increased palatability of silage.

Our information on various aspects of pasture agronomy is yet inadequate. The carrying capacity of our pastures has not yet been critically determined. The proper management for maximum efficiency and nutritive value remains to be studied. Grass/legume combinations and methods of pasture establishment and fodder conservation warrant more detailed investigation. Intensive research in these diverse fields will provide the basis for improvement in grassland farming in the dry zone.

Acknowledgements

I am grateful to Mr. P. Pemadasa for the chemical analyses.

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SOME STUDIES ON RUN-OFF AND INFILTRATION *

By

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THE RELATIONSHIP between rainfall and run-off is most conveniently understood in terms of the infiltration characteristics of the soil. This approach has been developed by Horton and others (1-3) and is widely used today in the planning of soil and water conservation measures. Hardly any experimental work has been done on the infiltration characteristics of soils under Ceylon conditions. During the *maha* season 1957-58, some preliminary work was carried out at Maha Illuppallama with a view to elucidating the run-off and infiltration pattern of soils under dry zone conditions.

Run-Off, Infiltration and Soil Loss on Small Plots

Measurements of run-off and soil loss were made on plots measuring 60 ft. by 12 ft., on a gradient of 5 per cent situated on the upper slope of a soil catena of a typical dry-zone catchment basin. Each plot was bounded by a brick and cement border which rose about 8 in. above the ground, and extended below about one foot. The run-off and soil loss were measured by a device based on an apparatus used by Russel (5), which measures total run-off. Measurements of the rates of run-off could not be made due to lack of suitable equipment.

Readings of the daily total of run-off and soil loss were taken every morning, simultaneously with the daily total of rainfall. Four plots were used in the experiment and they had the following treatments :

Plot A. Sorghum/pigeon pea—with a mulch of sunhemp residue
Plot B. Sorghum/pigeon pea—clean cultivated
Plot C. Cotton—with a mulch of sunhemp residue
Plot D. Cotton—clean cultivated.

The data of rainfall, run-off and soil loss are given in Table 1, while in Table II are given the highest rainfall intensities of the main *maha* showers, together with the duration of each intensity.

* Contribution No. 8 from the Division of Dry Zone Research.

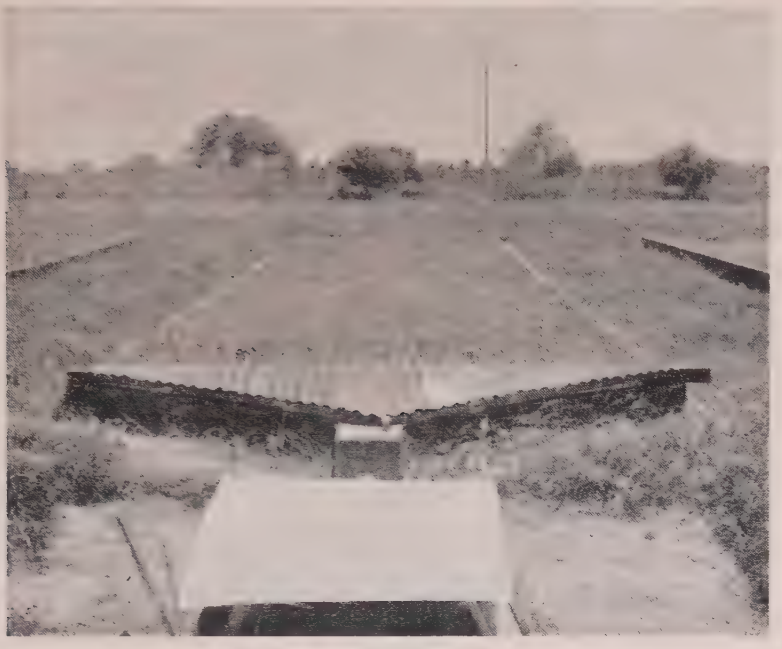
The difference between total rainfall and run-off is more or less equal to the total infiltration, except for the small showers where this difference is somewhat more than the actual infiltration due to the interception of part of the rainfall by the vegetation.

Following the rainfall of 1.43 in. on September 30, all four plots were mamoty tilled. On plots A and C a mulch of sunhemp residue was evenly spread on the surface. Approximately 30 lb. (air dry weight) of residue was spread on A, and 60 lb. on C.

The initial rains were completely absorbed by the dry soil on all four plots. Run-off first occurred with the rainfall of 2.68 in. on October 20, on plots B and D. The reaction of the soil surface to the initial rains on plots B and D differed markedly from that on A and C. This behaviour of the soil surface was investigated using splash samplers. Three 'splash samplers' were placed in each plot. Every morning, the weights of soil splashed into the samplers were recorded. The weights of soil collected are given in Table III.

There is a clear difference between the weights of soil splashed on the clean cultivated plots as compared with those on the mulched plots. Visual observation showed that the initial loose surface structure or tilth produced by tillage rapidly disappeared on the clean cultivated plots B and D, and a relatively impervious surface was produced. On the other hand in the mulched plots A and C, the soil surface retained its open structure. The surface sealing of clean cultivated soil by the initial high-intensity showers is evidently the result of raindrop impact on the soil aggregates, breaking them up into their constituent particles and subsequently re-arranging of the latter to form a closely packed, impervious layer at the surface. The infiltration capacity of the soil is thus greatly reduced, and the result is an increase in run-off and soil loss. The process which leads to surface sealing in soil may properly be called 'raindrop erosion'.

The effects of surface sealing are clearly reflected in the run-off figures for the rains of October 22 and the following days. This run-off carried considerable quantities of soil from the clean cultivated plots, as shown in Table I. This soil is derived mainly from sheet erosion on the plot. It is likely that run-off water also causes a certain amount of surface sealing. On the other hand, rain-drop erosion would decrease in a shower which produces considerable run-off for in such a case, the raindrops would be striking, for the most part, a layer of water and dissipating their energy on the water. Thus, the rainfall of 2.68 in. on October 20, produced 33.6, 57.5, 16.1, and 88.7 grams respectively on the four plots, A. B. C. and D. while the shower of



Device to measure run-off and soil loss as employed at Maha Illuppallama.

4.09 in. on October 22 produced 10.81, 24.0, 10.6 and 18.7 grams respectively on the same plots.

Splash values decreased as the season advanced, and by about the end of November, they became negligible; splash measurements were then discontinued. This decrease was due partly to the completion of surface sealing by the combined action of raindrops and run-off water, and partly to the protection afforded by the growth of weeds and the crop itself.

Towards the end of the season the quantity of run-off from similar rainfalls tends to increase and at the same time the difference in run-off between the mulched and clean cultivated plots tend to narrow. During the heavy rainfalls of December 24, 25 and 26, it was observed that the run-off from all plots was more or less the same, and at a rough estimate amounted to more than 75 per cent. of the total rainfall.

On these days exact measurements could not be made as the measuring apparatus itself went under water. It would appear that factors other than those of the soil surface influenced the run-off during this period. Measurements of the water table level showed that it was within a few feet of the surface before December 24, and

almost at the surface on December 25 and 26. Evidently the run-off pattern towards the end was influenced by the saturation of the regolith and rise of the water table.

Permeability of the Soil Profile

In order to elucidate the role of sub-surface drainage in relation to run-off and infiltration, measurements were carried out on the permeability of these soils by the method of Johnson, Frevert and Evans (7). The method was simple and provided only measurements of saturated permeability below the water table. The *maha* season 1957-58 was particularly favourable for these determinations as the water table rose near the surface in all land classes at the research station. In the method used an auger hole is dug, 4 inches in diameter and of the required depth. Seepage water which collects in the hole is pumped or otherwise taken out two or three times to minimise the effect of puddled soil at the bottom of the hole. The time taken for the water to rise a distance of about 1 or 2 inches at the bottom of the hole is then measured. These measurements and the dimensions of the hole are related to the permeability coefficient according to the equation of Johnson, Frevert and Evans.

Some measurements were also made of the rate of outflow of water from an auger hole (in which a constant level of water is maintained inside) into an unsaturated soil profile. The results obtained from both these methods showed that there was a variation in the drainage status of the 'B' horizon in the different land classes. Both methods indicated that in one catchment the upper slopes were about 10 times as well drained as the lower slopes. Values of permeability ranged from 0.2 to 7.0 in. per hour, while the values of outflow of water from an auger hole ranged from 150 to 1350 cc per hour. Similar variations were noted for the other catchments.

The permeability coefficient of the 'B' horizon of the land class on which the run-off plots were situated was 1.2 in. per hour.

Infiltration Capacity

Some experiments were carried out during the *yala* season 1957 to determine the influence of different crop rotations on the infiltration capacity of soil. Infiltration capacity was measured by the ring-infiltrometer method ; the ring used was 12 in. in diameter and about 8 in. high. The ring was pushed into the soil to a depth of 5 in. with a jack against the weight of a tractor. Preliminary experiments showed that on the research station soils the rate of infiltration became more

or less constant by the third hour from the commencement of an experiment. The third hour rate of infiltration was therefore taken in all cases, for the purpose of comparing the different crop rotations. Four rotations were studied on 1/20 acre plots. The rotations were as follows :—

Year	*Rotation A*	*Rotation B*	*Rotation C*	*Rotation D*
1st	Brachiaria	Sorghum / Pigeon pea	Velvet Bean	Cotton
2nd	Brachiaria	Velvet Bean	Pigeon pea	Sorghum / Pigeon pea
3rd	Brachiaria	Cotton	Pigeon pea	Groundnut / Gingelly
4th	Sorghum	Sorghum	Sorghum	Sorghum
5th	Sorghum	Sorghum	Sorghum	Sorghum

About 80 separate determinations were carried out. The averages of the results are given below :

	A	*B*	*C*	*D*
Av. Infiltration capacity (in./hr.)	0·21	1·20	0·71	0·83
Standard Deviation	±0·096	±0·478	±0·281	±0·353

An unexpected feature of the results was the low value of infiltration capacity or the Bracharia plots as compared with the other plots.

Discussion

To secure a satisfactory basis for the planning of soil and water conservation in Ceylon's dry zone, more systematic and comprehensive studies must be carried out with better equipment and techniques. But even the present data permit certain broad generalizations. Raindrop erosion caused by the initial, high-intensity rains of the *maha* season is undoubtedly of considerable importance in the dry zone. One of the methods of reducing run-off and soil erosion would be to evolve suitable agronomic practices which will protect the soil from raindrop impact and surface sealing. Run-off which is primarily due to poor disposal of water within the soil profile cannot, however, be adequately reduced by agronomic practices carried out at the surface. In order to deal with such run-off, agronomic measures must be supplemented and supported by suitable mechanical conservation methods which dispose of surface run-off in a non-erosive manner.

The following subjects need investigation if soil conservation problems are to be more completely comprehended and solved :

(*a*) The infiltration characteristics of soils and their variation under different cultural and cropping systems.

(*b*) The permeability characteristics of soils.

(*c*) The soil factors involved in the process of raindrop erosion.

(*e*) The influence of cultural and cropping practices on raindrop erosion.

(*f*) The susceptibility of soils to flow erosion and the influence of cultural and cropping practices on this process.

(*g*) The climatological factors which influence properties of soils.

Summary

Some preliminary work of a quantitative nature on run-off, infiltration and soil loss, carried out at Maha Illuppallama is reported. This work indicates that the initial high-intensity rains of the *maha* season cause raindrop erosion and surface sealing on clean—cultivated soil ; reduced infiltration and increased run-off and soil loss follow. Suitable agronomic measures can prevent this erosion damage. The rains of the latter part of the *maha* cause run-off on account of a reduction in the infiltration that results from the saturation of the soil profile. Suitable mechanical conservation measures are necessary to prevent flow-erosion during this part of the season. It would therefore appear that absorption of rain water as well as disposal of the excess play an equal part in the dry zone.

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TABLE 1.—Rainfall, Run-off and Soil Loss

Date	Rainfall	1,500 lb. mulch per acre PLOT 'A'		Clean Cultivated PLOT 'B'		3,500 lb. mulch per acre PLOT 'C'		Clean Cultivated PLOT 'D'	
		Run-Off	Soil Loss from Plot (Kilograms)	Run-Off	Soil Loss from Plot (Kilograms)	Run-Off	Soil Loss from Plot (Kilograms)	Run-Off	Soil Loss from Plot (Kilograms)
	(in.)								
30th September, 1957 ..	1·43	—	—	—	—	—	—	—	—
12th October, 1957 ..	0·54	—	—	—	—	—	—	—	—
18th October, 1957 ..	1·34	—	—	—	—	—	—	—	—
20th October, 1957 ..	2·68	—	—	0·03	0·29	—	—	Trace.	—
22nd October, 1957 ..	4·09	0·81	19.5	1·65	49·3	0·52	7·95	2·23	56·93
27th October, 1957 ..	1·58	0·13	1.13	1·16	4·35	0·04	0·08	1·24	7·46
30th October, 1957 ..	0·36	—	—	—	—	—	—	0·03	—
2nd November, 1957 ..	0·54	—	—	—	—	—	—	0·03	·02
4th November, 1957 ..	5·40	0·72	6.74	2·00	49·3	0·55	4·77	3·70	80·00
5th November, 1957 ..	0·25	—	—	—	—	—	—	0·04	—
6th November, 1957 ..	0·82	—	—	0·18	—	—	—	0·13	—
7th November, 1957 ..	0·87	0·04	—	0·20	—	0·04	—	0·11	—
14th November, 1957 ..	0·84	—	—	0·14	·76	—	—	0·18	·30
17th November, 1957 ..	0·57	—	—	—	—	—	—	0·17	—
18th November, 1957 ..	1·69	—	—	—	—	—	—	—	—
19th November, 1957 ..	0·40	—	—	—	—	—	—	—	—
20th November, 1957 ..	0·37	0·01	—	0·29	6·6	0·01	—	0·13	0·53
21st November, 1957 ..	0·28	—	—	0·11	·10	—	—	0·04	0·03
22nd November, 1957 ..	0·78	—	—	0·26	·26	—	—	0·16	0·29
25th November, 1957 ..	1·77	—	—	0·90	1·55	—	—	0·62	2·21
29th November, 1957 ..	1·32	—	—	0·85	2·31	—	—	0·50	0·68
4th December, 1957 ..	1·36	—	—	0·63	3·64	—	—	0·43	·27
6th December, 1957 ..	1·98	0·64	—	1·72	4·60	0·07	—	1·02	1·87
10th December, 1957 ..	1·55	0·14	—	0·89	·48	0·02	—	0·44	1·33
11/12th December, 1957 ..	1·65	0·06	—	1·14	1·74	0·02	—	0·44	·28

TABLE 1.—contd.

Date	*Rainfall*	*1,500 lb. mulch per acre PLOT 'A'*		*Clean Cultivated PLOT 'B'*		*3,500 lb. mulch per acre PLOT 'C'*		*Clean Cultivated PLOT 'D'*	
		Run-Off	*Soil Loss from Plot (Kilograms)*	*Run-Off*	*Soil Loss from Plot (Kilograms)*	*Run-Off*	*Soil Loss from Plot (Kilograms)*	*Run-Off*	*Soil Loss from Plot (Kilograms)*
	(in.)								
12th December, 1957 ..	1·59	—	—	—	—	0·44	—	1·36	—
17th December, 1957 ..	3·48	0·52	·84	2·50	5·10	0·47	·14	1·52	·61
18th December, 1957 ..	0·81	—	—	0·25	·01	—	—	0·09	·02
19th December, 1957 ..	1·18	—	—	0·35	·13	—	—	0·30	—
20th December, 1957 ..	2·17	0·33	·29	1·03	7·21	0·23	·22	0·63	·06
21st December, 1957 ..	3·29	0·36	·57	2·84	6·75	1·05	·89	2·57	—
23rd December, 1957 ..	2·87	0·47	—	1·00	—	0·16	—	—	—
24th December, 1957 ..	8·06	—	—	—	—	—	—	—	—
25th December, 1957 ..	8·55	—	—	—	—	—	—	—	—

TABLE II

Higher Rainfall Intensities of the Main Maha *Season Showers*

Date	*Intensity in in./hr.*	*Duration in mins.*
30th September	1·90	35
	0·66	20
20th October	0·93	75
22nd October	0·50	60
	2·03	85
27th October	2·64	25
4th November	3·50	70
	1·36	15
12th December	1·68	20
	1·94	35
20th December	0·72	50
21st December	1·18	25
	2·40	25
	0·64	15
24th December	0·60	90
	0·95	35
	1·68	25
25th December	0·68	60
26th December	0·23	60
	0·14	60

TABLE III.—Weights of Soil splashed in Grams

Date	*Rainfall*	*PLOT A*	*PLOT B*	*PLOT C*	*PLOT D*
5th October	—	—	—	(Soil tilled with mammoty 60 lb. mulch spread on surface)	(Soil tilled with mammoty)
9th October	—	(Soil tilled with mammoty 30 lb. mulch spread on surface)	(Soil tilled with mammoty)	—	—
12th October ..	0·54	14·4	26·0	10·0	31·0
15th October ..	0·11	0·62	1·1	0·1	0·6
17th October ..	0·30	3·48	5·0	(Cotton planted)	(Cotton planted)
				1·9	13·1
18th October ..	1·34	23·0	28·8	10·7	33·6
19th October ..	0·17	6·18	6·2	2·5	10·3
20th October ..	2·68	33·6	57·5	16·1	88·7
21st October ..	0·30	2·17	5·0	1·4	2·8
22nd October ..	4·09	10·81	24·0	10·5	18·7
24th October ..	0·28	?	?	?	?
26th October ..	0·13	0·96	1·4	0·7	1·3
27th October ..	1·57	12·7	16·3	13·2	17·0
29th October ..	—	(Pigeon pea planted)	(Pigeon pea planted)	—	—
29/30th October	0·22 0·36	6·5	12·4	6·8	11·0
2nd November	0·54	2·3	5·6	2·0	4·9
3rd November	0·28	0·9	2·1	0·4	1·9
4th November	5·40	(Sorghum planted)	(Sorghum planted)	?	?
5th November	0·25	2·3	4·8	0·7	3·7
6th November	0·82	2·5	3·5	0·9	2·5
10th November	0·30	trace	trace	trace	trace
14th November	0·84	6·5	15·0	2·9	6·6
17th November	0·57	2·4	9·5	1·0	1·8
21st November	0·28	0·4	0·9	0·6	5·0
28th November	0·37	0·5	0·1	0·2	0·8

METEOROLOGICAL REPORT

Summary for April-June 1958

ORDINARY monsoon weather prevailed over the Island during July. The winds were, however, not much moisture-laden, so that although monsoon rain was experienced in the south-western parts frequently, the daily falls were only light or moderate. There were a few days during the first half of the month, when the weather was dry even in the south-western parts. The greater monthly totals of rainfall occurred on the south-western slopes of the hills and were mainly below 20 inches. At the south-western coastal stations the rainfall was in the neighbourhood of 5 inches, while outside the south west quarter it was below 2 inches. About 60 stations, mainly in the north central parts, received no rain at all. The rainfall was below normal, almost over the whole Island. Greater deficits, which were of the order of 15 inches, occurred on the south-western slopes of the hills. Slight excesses were found on the east side and in the north.

Normal monsoon conditions prevailed over the Island during August. Most of the rain was experienced in the hill-country. Thunderstorms resulted in rain in the north and east during the first ten days of the month. The greater monthly totals of rainfall occurred on the south-western slopes of the central hills, the greatest being 37.31 inches at Kenilworth. The lowest totals were recorded in the north, north-west and south-east. Ten stations in these areas received no rain at all. The larger excesses of rainfall were experienced among the hills while a few were also recorded in places in the north and east. The largest of them was 18.90 inches at Weweltalawa. Several deficits were recorded in the south and west.

Very little monsoon rain was experienced during September but afternoon and evening thunder activity gave a fair amount of rainfall during the second half of the month. The greater monthly totals of rainfall were practically confied to the south-western slopes of the central hills and to parts of the south-western low-country. The highest total was 14.80 inches at Gilimaley. The lowest totals were recorded in the north and north-west, as many as 50 stations reported no rainfall at all. The larger excesses of rainfall of the order of 5

inches were experienced in the Passara area and in the eastern coastal region. Deficits were experienced in most of the other places, those of the order of 15 inches occurring in Watawala Area.

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METEOROLOGICAL REPORT FOR THE QUARTER JULY TO SEPTEMBER, 1958

	JULY								
	Temperature				Humidity		Rainfall		
	Mean Maximum	Offset	Mean Minimum	Offset	Day	Night (from Min. Temps.)	Total	Offset	Number of days
Anuradhapura ..	92·5	+1·6	76·5	+0·7	63	91	0·09	—1·23	2
Badulla ..	88·4	+2·2	64·0	—0·3	58	91	0·40	—1·77	2
Batticaloa ..	93·1	+1·2	77·3	+0·4	64	80	0·93	—0·11	6
Colombo ..	86·0	+1·3	79·0	+2·1	75	82	1·47	—4·02	10
Diyatalawa ..	79·4	+1·5	62·9	+0·4	60	76	1·53	—0·43	7
Galle ..	8·51	+1·4	79·1	+2·5	78	80	3·05	—3·29	18
M' Illuppallama ..	91·4	+1·8	75·7	+0·8	65	88	0·19	—1·24	4
Hambantota ..	86·4	—0·9	77·3	+1·0	79	91	3·39	+1·38	6
Jaffna ..	86·1	0	80·7	+0·9	79	82	0·15	—0·40	1
Kandy ..	83·0	+1·9	70·9	+1·1	71	87	2·05	—3·84	11
Kankesanturai ..	90·2	+0·3	80·0	+0·9	70	85	1·18	+0·64	2
Kurunegala ..	88·2	+1·9	76·3	+1·1	72	88	1·97	—1·91	11
Mannar ..	87·9	+0·6	80·6	+1·5	74	82	0	—0·35	—
Nuwara Eliya ..	67·8	+2·5	56·2	+1·3	77	83	3·87	—7·15	17
Puttalam ..	88·0	+1·8	79·4	+1·2	71	82	0·38	—0·61	2
Ratmalana ..	87·1	+2·4	78·5	+2·2	78	89	1·50	—3·96	16
Ratnapura ..	88·6	+2·0	75·3	+0·9	67	84	7·04	—5·73	23
Talawakele ..	71·1	+0·9	60·5	+1·0	84	91	4·93	—8·37	20
Trincomalee ..	94·9	+2·5	79·6	+1·6	57	76	1·22	—0·51	4

	AUGUST								
	Temperature				Humidity		Rainfall		
	Mean Maximum	Offset	Mean Minimum	Offset	Day	Night (from Min. Temps.)	Total	Offset	Number of days
Anuradhapura ..	89·1	—2·3	75·2	—0·3	70	91	2·25	+0·63	9
Badulla ..	85·3	—0·7	65·9	+1·4	68	92	28·5	—0·35	12
Batticaloa ..	90·4	0	76·0	—0·5	72	86	5·11	+3·16	10
Colombo ..	84·5	—0·1	77·8	+0·8	75	82	3·06	—0·97	16
Diyatalawa ..	76·9	—1·0	62·4	+0·7	71	86	5·08	+1·96	11
Galle ..	82·0	—0·6	76·7	0	81	84	6·33	+0·19	18
M' Illuppallama ..	89·0	—1·1	74·6	—0·6	71	90	2·59	+0·98	10
Hambantota ..	86·6	+0·3	76·6	+0·5	75	88	1·20	—0·24	7
Jaffna ..	85·6	+0·4	79·6	+0·3	77	87	1·95	+0·84	6
Kandy ..	80·3	—1·0	70·4	+0·7	78	90	7·40	+2·66	27
Kankesanturai ..	88·1	—1·9	78·8	—0·2	75	89	3·07	+1·81	8
Kurunegala ..	85·4	—1·4	75·1	+0·2	78	91	3·82	+0·20	24
Mannar ..	86·8	—0·6	79·0	+0·3	77	86	0·33	—0·33	4
Nuwara Eliya ..	65·1	—1·0	56·6	+2·2	84	85	9·30	+1·79	26
Puttalam ..	87·1	+0·5	78·1	+0·2	72	82	0·74	+0·09	5
Ratmalana ..	85·2	0	77·3	0	79	89	3·72	+0·24	13
Ratnapura ..	85·9	—0·9	74·4	+0·2	71	84	11·89	+0·50	28
Talawakele ..	68·6	—2·3	60·1	+0·9	89	94	10·59	+0·51	28
Trincomalee ..	90·6	—1·5	77·2	—0·1	66	80	6·06	+2·45	10

	SEPTEMBER								
	Temperature				Humidity		Rainfall		
	Mean Maximum	Offset	Mean Minimum	Offset	Day	Night (from Min. Temps.)	Total	Offset	Number of days
Anuradhapura ..	95·0	+3·2	75·4	+0·4	57	88	0·27	—3·49	2
Badulla ..	88·3	+2·6	64·2	—0·1	62	91	2·29	—2·20	10
Batticaloa ..	90·9	+1·2	76·3	+0·1	71	86	0·74	—1·65	6
Colombo ..	86·5	+1·1	77·4	+0·9	72	84	1·88	—4·96	11
Diyatalawa ..	79·1	+1·3	60·6	—0·3	65	86	2·61	—1·80	14
Galle ..	82·9	+0·1	77·0	+0·3	79	84	7·72	—1·09	15
M' Illuppallama ..	94·4	+3·2	75·3	+0·6	56	84	Trace	—3·05	Nil
Hambantota ..	86·6	+0·1	76·8	+0·7	74	88	0·43	—2·33	5
Jaffna ..	87·0	+0·8	80·5	+1·2	77	85	0·02	—2·51	1
Kandy ..	84·0	+1·8	68·7	+1·2	68	92	0·98	—5·00	10
Kankesanturai ..	91·4	+1·6	79·7	+0·6	67	85	0·94	—2·03	6
Kurunegala ..	90·1	+2·4	75·7	+1·4	65	88	1·98	—3·62	9
Mannar ..	88·3	+0·6	79·7	+0·8	75	82	0	—1·24	0
Nuwara Eliya ..	69·0	+2·2	54·5	+1·2	77	82	1·69	—6·55	17
Puttalam ..	89·6	+2·6	78·7	+0·9	65	80	0·02	—1·56	1
Ratmalana ..	86·5	+0·8	77·0	+0·6	77	91	3·61	—3·23	12
Ratnapura ..	88·9	+1·7	74·1	+0·6	65	84	8·02	—3·50	19
Talawakele ..	—	—	—	—	—	—	—	—	—
Trincomalee ..	93·3	+1·2	77·5	+0·4	60	78	8·22	+4·79	7